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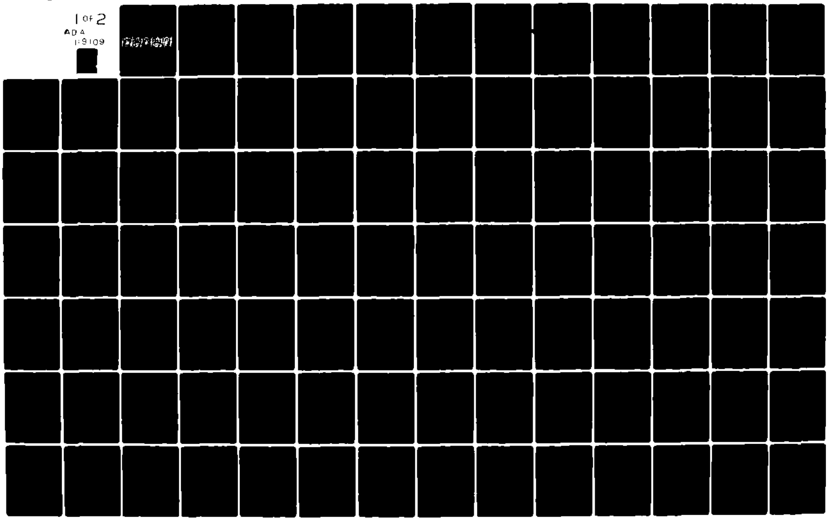

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CONSTRUCTIVE INTERACTION

Naomi Miyake

CENTER FOR HUMAN INFORMATION PROCESSING

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Constructive Interaction

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ABSTRACT

Two person, purposeful conversational interactions were analyzed in order to identify conditions that make such interactions constructive--constructive in the sense that participants acquire new understanding about the topic. Two situations were examined. In one, a professional researcher explained her data to a statistician. In the other, three groups of two people cooperated with each other to figure out how a sewing machine made its stitches.

A framework called "a function-mechanism hierarchy" was developed to capture a course of understanding in the sewing machine interactions. According to this framework, understanding proceeds from global, functional understanding to local, mechanistic understanding by descending "levels." The subjects' conceptual point-of-view was related to this course of understanding. Point of view shifted more when the subjects felt they were not understanding, and this shift appeared to help them descend the levels. People corrected more errors when they reflected the current level of understanding; errors were not corrected when they belonged to already known levels.

For both statistics and sewing machine interactions, the issue of "focus" was identified to be important in understanding. When a schema needs to be changed, it seems necessary to have a global understanding of the old schema as well as attention to the place where the change is to take place. Two person interactions have virtues because the participant can take different roles in the interaction and divide the labor: While one person leads the interaction by engaging in the local task, the other can observe and provide help by criticizing and bringing up new motions.

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1: INTRODUCTION

My goal for this series of research is to identify conditions which make a conversational interaction constructive--constructive in the sense that the participants can find the way toward the accomplishment of what they wanted to accomplish. I focus on purposeful conversation, the situation in which a definite goal exists for the participants. The type of accomplishment I deal with is to promote understanding, to come to know what was not known.

In a two-party cooperative interaction all participants pursue their own interests, and the two together try to reconcile differences between their views. The participants' verbal presentations make some of the personal knowledge structure visible. The interaction situation provides some hints to observation of two thinking processes, providing a semi-transparent window through which a scientific eye can "see" the changes in knowledge structures. My task has been to develop a framework to represent these changes and deduce conditions necessary for such changes.

In cognitive science, studies about conversations or dialogues have been seen as a natural extension of studies about sentence processing (Robinson, J., 1980; Robinson, A, Appelt, Grosz, Hendrix, & Robinson, J., 1980; Grosz, 1977; Levin & Moore, 1978; Reichman, 1978; Schank, 1977). Interacting "plans" and "intentions" are the key notion for some researchers, who have tried to formalize comprehension processes of speech acts and stories (Cohen & Perrault, 1979; Bruce and Newman, 1978). Hobbs and Evans (1980) applied the notion of the planning mechanisms developed in artificial intelligence to understand the conversation.

In these studies, models are provided to clarify the <u>communication</u> process, rather than the <u>construction</u> process. For example, notions like "focusing" (Grosz, 1977; Reichman, 1978; Sidner, 1981), "planning" (Cohen & Perrault, 1977; Hobbs & Evans, 1980), and "the Dialogue Games" (Levin & Moore, 1978) are introduced to define mechanisms that allow one to successfully comprehend ongoing conversation. These do not attempt to specify the "constructive" aspect of conversation through which the conversants reach some new outcome. The interest has been in the structure of discourse, not the structure of knowledge.

This emphasis occurs because the studies have focused on situations either where no immediate task is apparent (Reichman, 1978; Hobbs & Evans, 1980) or where the task is so defined that the goals and the means to achieve those goals are clear, such as the air compressor building situation studied by the SRI project (Robinson, J., 1980; Robinson, A, Appelt, Grosz, Hendrix, & Robinson, J., 1980; Grosz, 1977) or the "helping" situations studied by Levin and Moore (1978). In the purposeful interaction situation that I have studied, the goals are to create a new understanding for both participants, and the method and route had to be searched for.

Studies of changes of the participants' knowledge structures are not common. There are no tools easily available to represent a subject's personal knowledge and to follow its change. Theoretical work on how learning should occur (e.g., Rumelhart & Norman, 1981) is insightful, but the precise documentation is yet to come. Strictly domain-specific attempts to follow the path of learning have begun to appear ("microworld organization" figures by Lawler, 1981; "learning paths chart" by diSessa, 1982), but as yet, they are not very general.

I have observed some purposeful, constructive interactions and tried to invent a scheme for the analysis of the understanding processes through the interaction. In the following chapter, I describe a preliminary analysis on an interaction on a statistics problem. A scheme to follow the knowledge content change was devised and applied, yielding some preliminary observations about conditions for such a change. When a schema needs to be changed, it seems necessary to have a global understanding of the old schema, as well as attention on the place where the change is to take place. The interaction was useful, but not easy to replicate: the problem was unique to the researcher, and once the solution was known, she could not repeat the same role. To investigate the phenomena more generally, I needed another situation.

For my task I chose the topic of determining how a sewing machine made its stitches. I collected extensive interactions produced by three pairs of subjects, and developed a framework to capture the course of their understanding. According to this framework, the understanding proceeds in descending levels, from global, functional understanding to local, mechanistic understanding. In Chapter 3 I describe this framework and relate it to an observation on shifts of the subjects' point of view: The point of view shifted more when subjects felt they were not understanding. This shifting appeared to help them descend levels, thus promoting their understanding.

In Chapter 4 an error detection pattern in naturalistic conversations was identified in the same set of protocols used in Chapter 3. People appeared to detect more of their errors when the errors belonged to the current level of understanding; errors were not caught when they belonged to the already known levels.

In the last chapter I link the analyses on the statistics problem and the sewing machine problem and list four generalizable observations of the factors responsible for constructive interactions. I suggest that in my two person interactions the subjects appeared to take different roles in the interaction based on their different focus: While one person led the interaction by engaging in the local task, the other observed and provided help by criticizing and bringing up new motions. This last chapter is also a proposal for further work.

2: PRELIMINARY ANALYSIS

2.1. Introduction

This chapter reports the first attempt I made to identify conditions that makes interactions constructive. A tool called "content sketch" was developed to capture the change occurring within a two person interaction. Although the analysis was preliminary, some conclusions were reached which were relevant for the research reported in the following chapters.

The situation I have analyzed is one in which two people interacted over several sessions. One person was an experienced, professional researcher (R) who had just completed an experiment. The other was a skilled but non-professional statistician (S) who was going to do the data analysis. The participants knew why I was recording the conversation.

A statistical consulting situation has some advantages. The participants' intentions are reasonably well known, and their language (particularly statistical terms and numbers) is reasonably easy to interpret.

This particular interaction had an important feature for the purpose of my research: R had not fully decided what should be done with her data. Rather, through the entire course of the interaction, she remained flexible enough to explore new ways on her own part as well as to allow S to make suggestions. This way, they reached a goal that had not been obvious to either of them at the beginning of their interaction. In other words, they constructed a new design of analysis through their interactions.

The overall intention of the participants was clear and well understood: R wanted to have her data analyzed. From my preliminary interview with each one of them, I had clues about how much information they had and what kind of expectation they held for the forthcoming interaction, which provided a crude representation to start the enterprise.

2.2. Method

2.2.1. Terminology

The words subjects and experiment refer to the data and situation being analysed by the participants. I use the terms "participants" and R and S to refer to the interaction.

2.2.2. Situation

R and S were asked to interact naturally to accomplish their task--to design an analysis for R's data. This was a real task for them, not merely done for my observation: S actually did the analysis and R published a paper reporting the result. The author was present observing the situation. The entire interaction took some forty-five minutes. The whole interaction was tape-recorded and transcribed. Only the verbal aspect of the transcription has been analyzed.

2.2.3. Topic of the interaction

R was interested in the different roles that nouns and verbs play in sentence comprehension. Her hypothesis was that verbs are more "relational" and thus change their meaning according to the accompanying nouns. Nouns are not as flexible. R tested this hypothesis by using a paraphrase-restore design: one set of subjects paraphrased some original noun-verb combinations (in the form of sentences) and the other set of subjects tried to restore the original nouns (or verbs) given only the paraphrases. R hoped to argue that the verbs were harder to be restored than the nouns, implying that the verbs tend to change meaning more than the nouns.

The experimental design for the experiment being discussed is diagramed in Figure 1. Numerical details of the experimental design are given in Appendix 1. A raw data format was present in front of the participants through the entire course of the interaction. Appendix 2 shows the format.

In this design, there are at least two factors that require analysis. The form-class comparison (nouns versus verbs) is the main concern. In addition, the stimuli formed six sets which needed to be compared with one other for homogeneity. The number of subjects, seven per set, established a random factor. In my pre-interview with R, she revealed that she did not have a precise plan for the statistical analysis.

There were other points of concern for R. She was interested in the statistical interaction of form-class and noun-verb combinations she used as stimuli: verbs should change meaning more when they appear in an inappropriate noun-verb combination (e.g., an abstract noun combined with an animate verb) than when they appear in an appropriate combination (e.g., an animate noun combined with an animate verb). Approximately two-thirds of the forty-five minutes of interaction was devoted to settling this problem, which turned out to require a factor

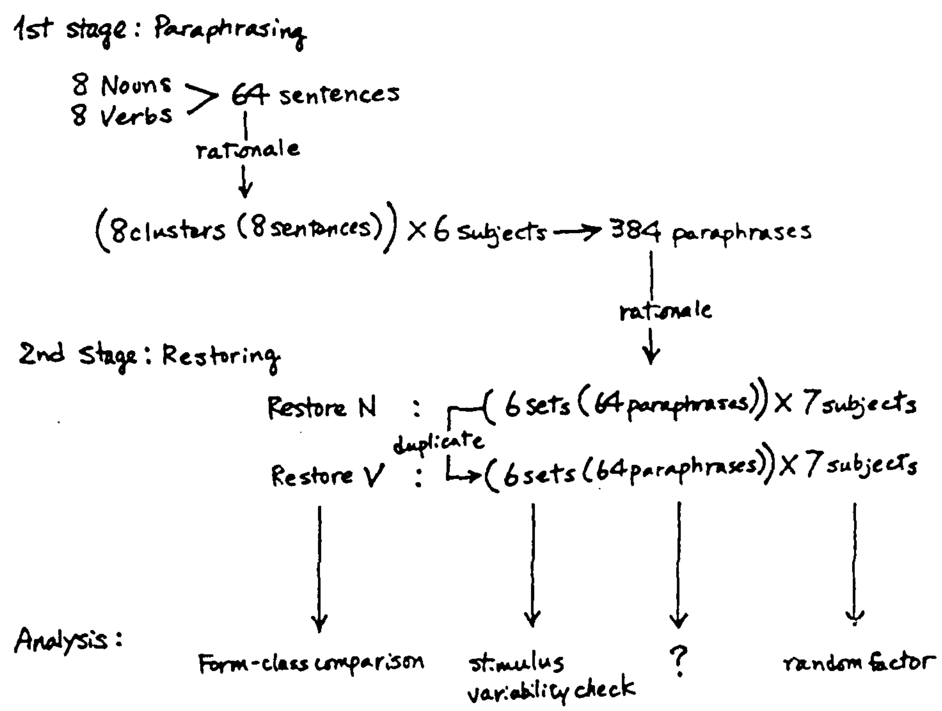

Figure 1. The design of the experiment.

of three levels of word-combination naturalness.

2.3. Preliminary results

2.3.1. Transcript

A transcript was prepared from the audio tape. Each line represents an utterance spoken in one breath. Lines are numbered from the beginning (1) to the end (1122).

2.3.2. Starting schemas

From previous interviews and the global intention of this interaction situation (i.e., R's data to be analyzed by S), I assume the two participants started with the following schemas:

1) R had a schema of her experiment (Figure 1). The diagram is drawn to indicate her order of presentation (from left to right) as well as the history of experimental steps taken (from top to bottom, each row representing one step). Her analysis design schema, which was not quite established at the beginning, is shown as an open end of the experiment schema.

2) S had a schema of her design for an analysis, also open, represented as a basic ANOVA schema with several lists of open slots: one slot for the names of factors to be analyzed and the others to register attributes such as the number of levels, whether it is a within or between subject factor, whether they have missing data, etc. I am concerned only with these slots, because which specific schema of ANOVA S had is not my main interest here.

2.3.3. Overall description of the interaction

Figure 2 summarizes what happened during the forty-five minutes. Summary descriptions of events are in capital letters, located on the time line roughly at the time they occurred, starting at the top and ending at the bottom. In the initial part of the session (the top of the figure), R explained her experiments, its procedures, data, and her plan for the simplest analysis (do a t-test comparing the noun group and the verb group). In the mid-session their interaction led them to a new design of analysis, a 2 X 2 ANOVA. In the end of the session, they polished up this design, leading them to a 2 X 3 ANOVA.

The key for the design is in the use of the phrase "combinations." (These usages are shown enclosed in rectangles in the figure.) In the old design, they were nothing more than the stimuli. In the new design, they had to be regarded as a factor. In the entire transcript, there are four occasions where either R or S mentioned "combination," once in the initial part of the session, three times in the mid-session. At the fourth such occasion, they agreed to take word combination as a factor for analysis and to negotiate the exact way of analyzing it. I focus my analysis on these four occasions.

2.3.4. Content sketch

As the first attempt to follow the content change in the interaction, a method called "content sketches" was devised. A content sketch consists of three parts: what is assumed to be R´s whole schema of the experiment; what has been verbalized by R; and what is "acknowledged" or assumed to be "registered" by S. Operationally, the term "acknowledged" means that an utterance by R was followed by a "casual" or "passing mode" response by R (see Weiner and Goodenough, 1977), such as "O.K." or "Uh huh." These responses do not guarantee that the information actually got into S´s knowledge schemas, but it is suggestive. Any verbalization by S will be regarded as "registered" in her knowledge.

Each content sketch represents a snapshot, frozen in time. The sketch changes with each utterance.

Each content sketch has three boxes, as shown in Figure 3. Suppose a content sketch was drawn at time t, to accompany the fictitious excerpt in Table 1. The top box illustrates R´s thinking process. It has R´s starting schema as its base (in light drawing, not fully drawn here for simplicity), with what she has verbalized so far indicated in shaded dark drawing. New concepts introduced by S and acknowledged by R are shown as additions to the base schema.

The bottom box contains S´s starting schema for analysis (in light drawing) with a large working space on which she builds a new schema about the experiment. For simplicity, I use the arrangement of R´s starting schema (which is not fully drawn here for simplicity) to lay out what can be deduced to have been registered (in dark shaded dark drawing) and acknowledged (in light shaded light drawing) by S by time t. What is registered to S´s starting schema is added to the schema (in dark shaded dark drawing). An assumption is made that S distinguishes conversation about experiment from that about analysis and treated them on different schemas.

Admittedly, a very conservative estimate is observed here, since there is no room for inferences made by S. I leave open the question whether (and how) we should represent those inferences in this kind of diagram.

In the middle of two areas I diagram the detailed verbal exchange at time t. It deals with what R verbalized (shaded) and what S verbalized (shaded). Correspondence between these verbalizations and S or R´s schemas are illustrated by dotted lines.

By drawing the content sketches at different times in the interaction, one can follow the changes in knowledge representation.

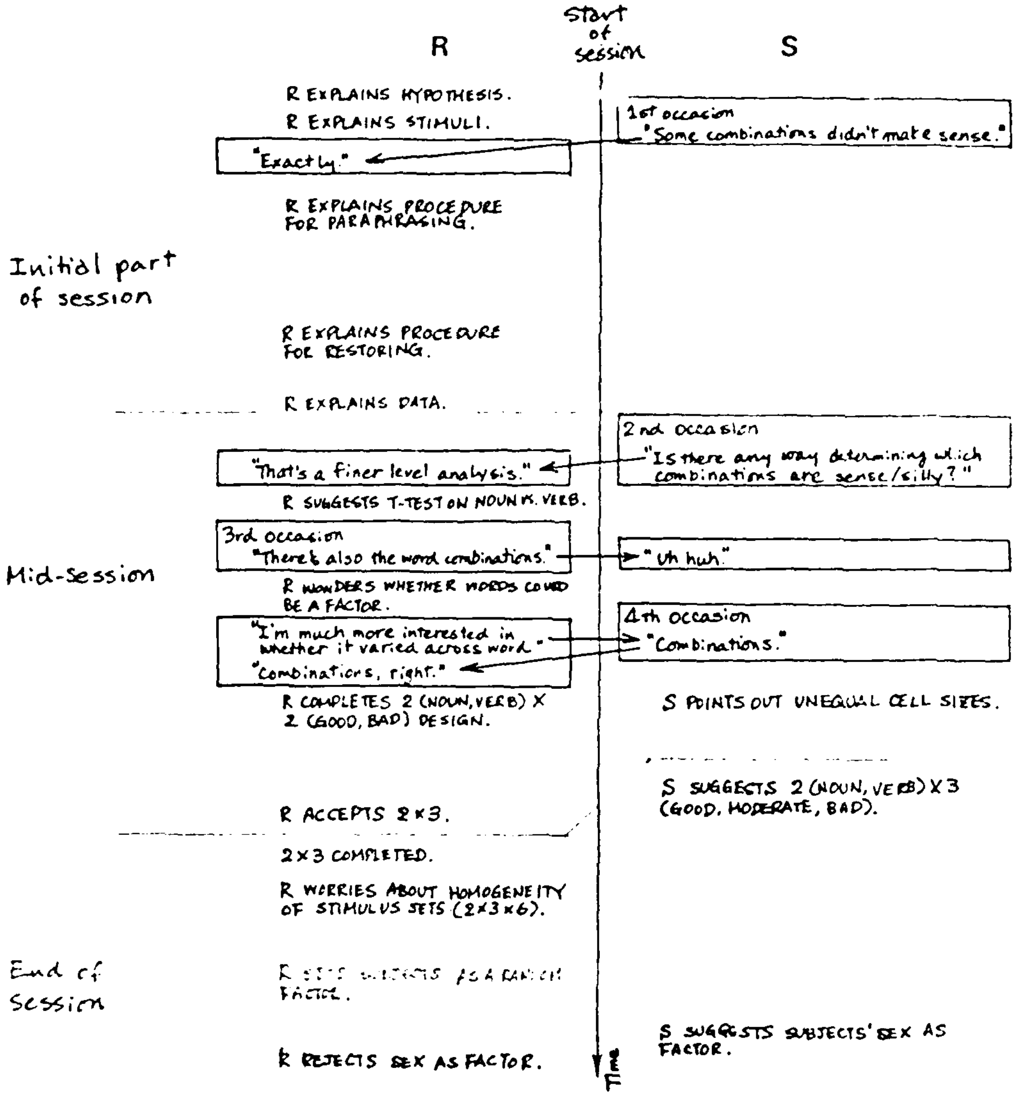

Figure 2. The overall course of the statistics problem interaction. R stands for researcher; S for statistician. Events are given in capital letters. Four occasions where the phrase "combination" was mentioned are enclosed in rectangles, with arrows connecting each initiation to its reply.

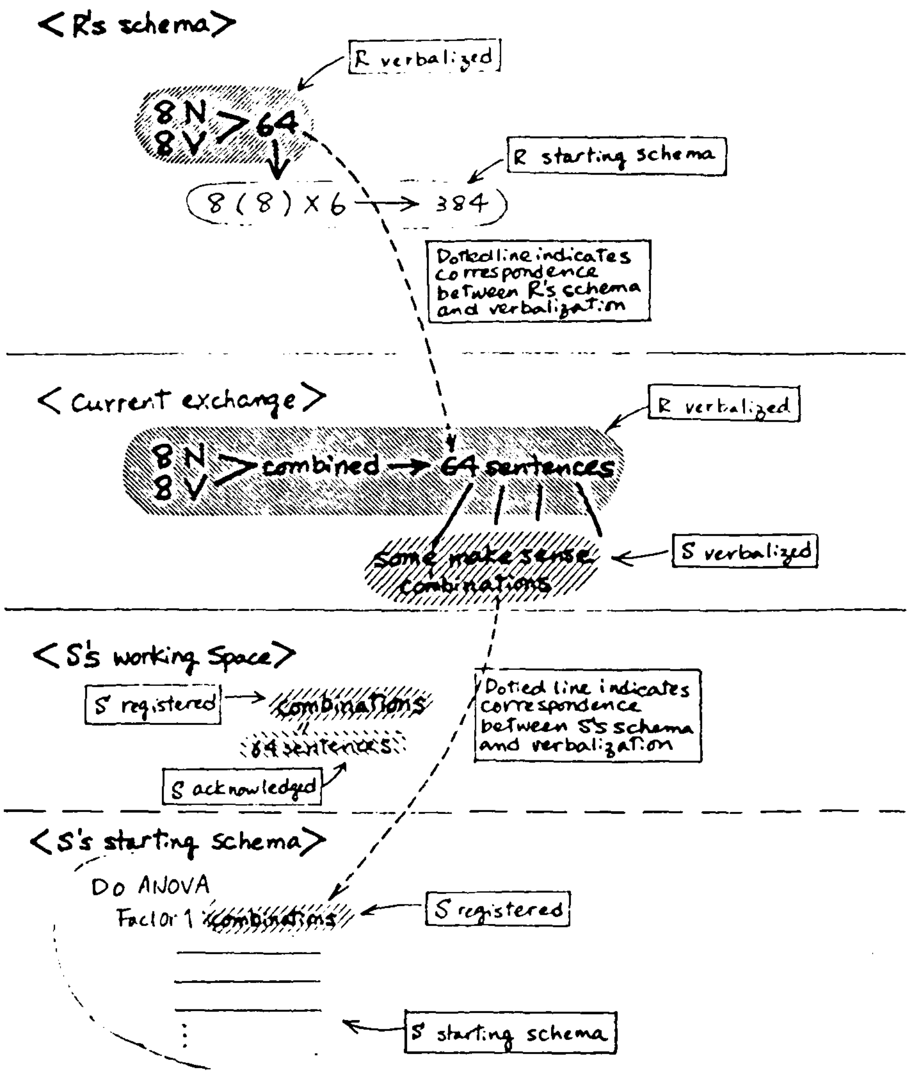

Figure 3. A content sketch.

Table 1

Fictitious excerpt for the content sketch in Figure 2
(R stands for researcher; S for statistician.)

R: I made 64 stimulus sentences, by combining 8 nouns and 8 verbs.

S: So only some of those word combinations made sense.

2.3.5. Schema change

To follow what exactly happened in the course of R and S reaching the new design of analysis, I draw content sketches for each occurrence of the "combination" phrase. Then I compare them to detect any conditions for such a change.

First occasion. The excerpt in Table 2 is the first appearance of the word "combinations" in my transcript. This is at a fairly early stage of the interaction and second "substantive" (see Weiner & Goodenough, 1977) utterance made by S. Her attempt to restate the nature of the word combinations on her own part can be seen as a trial to interpret the word combination as a possible candidate factor for analysis with two levels of making good sense and making no sense. Thus, in its content sketch shown in Figure 4, "word combination" is registered in design of analysis schema as a "possible factor candidate." There is no sign that R noticed that the notion of "word combination" was interpreted as such by S at this point. R knew sentences were word combinations and they differed in their naturalness. Thus, no addition is made to her schema. The two are, at this stage, working on two totally different schemas.

Second occasion. In the second occurrence of "combination" (Table 3 and Figure 5) R has finished laying out what she thinks to be the whole view of the experiment and asks S whether she "sees" her point. By replying "Yeah" to that inquiry, S feels obliged to review in her own terms what she thinks the experiment is all about, and goes back to what she has already registered. On the assumption that all she was interested in at the starting point of this interaction was collecting factor information usable for the analysis, it was natural for her to go back to the list of registered factors for this review (shown at the bottom of the sketch). Here S finds "word combinations." It is quite understandable that she started to clarify this word combination notion to make sure it was actually a factor. Her way of mentioning this, in the form of inquiry rather than of declarative (lines 363-365), indicates her doubt whether this is actually a factor. There are a lot of reasons for her doubt, as can be seen in the content sketch, because there has been no mention about the word combination since line 51--some 300 lines of conversation ago--which means that R has never used the term "word combinations" so far. The content sketch also shows that R and S have fairly different schemas for analysis.

S's question triggered R to consider he new issue. She tried several word combinations to see whether she could comfortably classify her stimulus sentences into "make-sense" combinations and "make-no-sense" combinations. R succeeds in this attempt, but rejects this level of analysis as a little finer and "we are not there yet." (line 427).

Third occasion. Table 4 and Figure 6 show the first occasion where R mentions the phrase, "word combinations." R has established one analysis, a t-test on the noun group and the verb group, and goes on to seek further factors. She finds sets of paraphrases and mentions paraphrases are also word combinations. However, she cannot find the

Table 2

"Word combinations": First occasion
(R stands for researcher: S for statistician.)

```
41:  R: th, the first thing that I did was
42:     make up a matrix
43:     of nouns and verbs
44:     of, this way,
45:     and there were eight nouns across here
46:     and eight verbs down there and you can make
47:     sixty-four sentences by combining them
47:     well so if you look at these the daughter agreed
48:     the politician agreed and the mule agreed
49:     the daughter worshiped the politician worshiped
        and so on
50:  S: okay so some of these combinations didn´t make sense
51:     while some other
52:  R: and some others exactly
53:     and they were deliberately chosen
54:     so some of the pairs go together well
55:     and some don´t go together at all
56:     so now you have these sixty-four sentences
57:  S: uh huh
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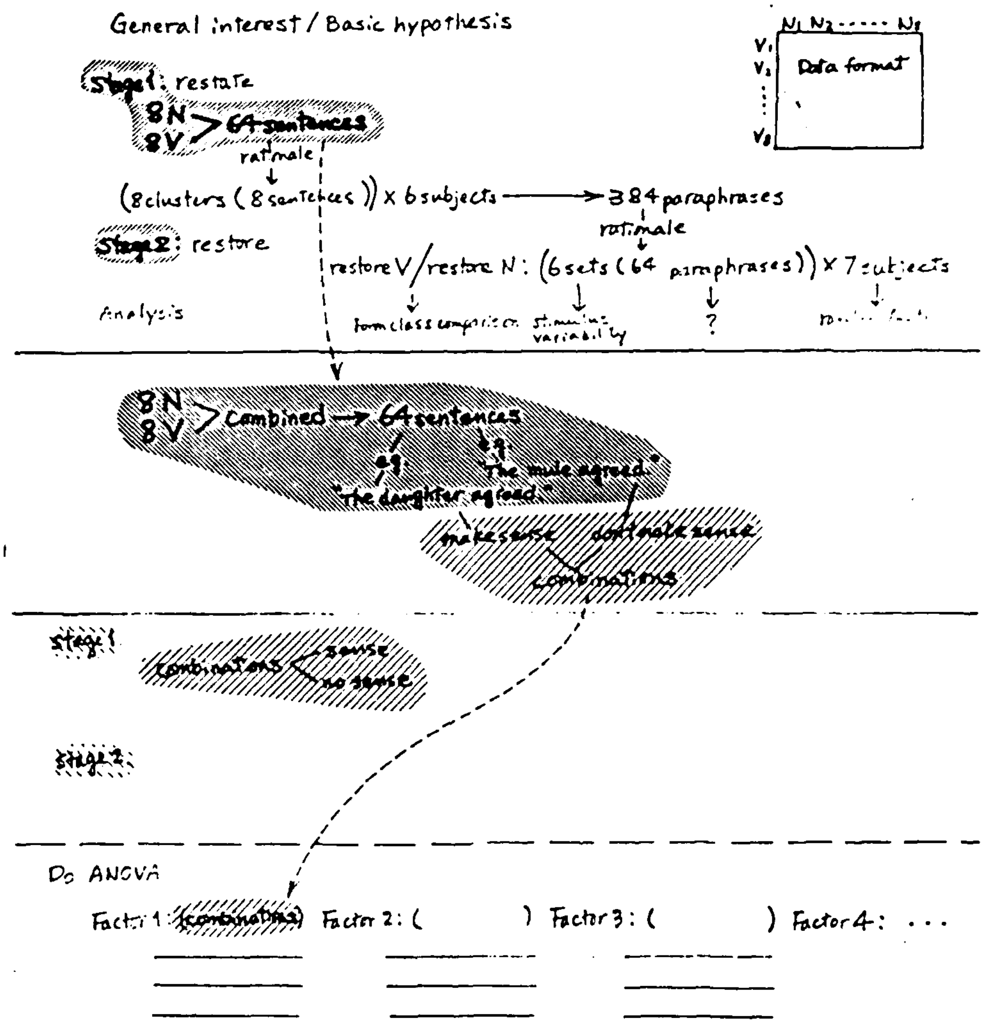

Figure 4. "Word combinations": First occasion.

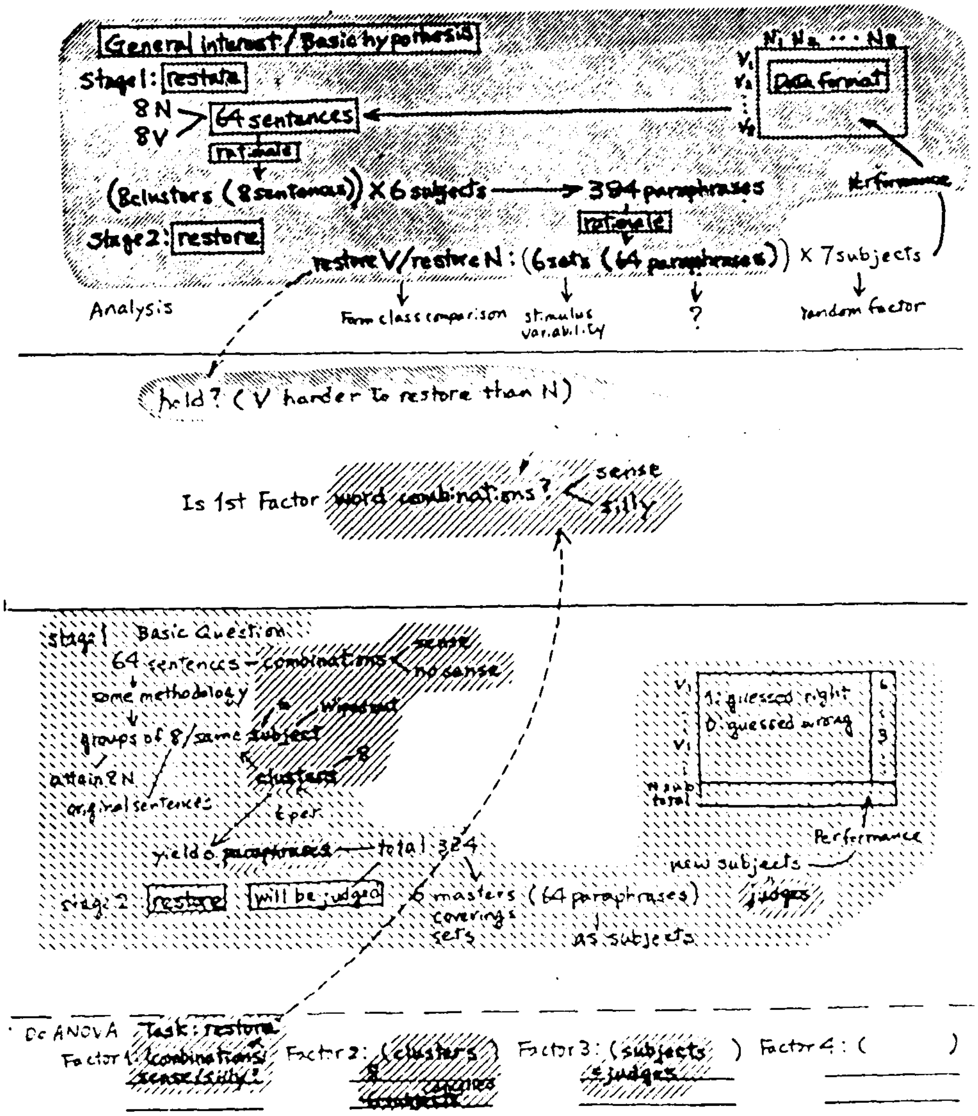

Figure 5. "Word combinations": Second occasion.

Table 3

"Word combinations": Second occasion
(R stands for researcher; S for statistician.)

356: R: and that's what
357: the analysis is to find out
358: whether that in fact holds on
359: R: see what I'm saying?
360: S: yeah I see what you're saying
361: okay
362: you want
363: is there any way uh
364: determining which combinations are sense
365: combinations and which combinations are silly combinations
366: R: yeah
367: well
368: that's a good question
369: and that's that's a a somewhat finer
370: level of analysis which I'd like to get to
371: but

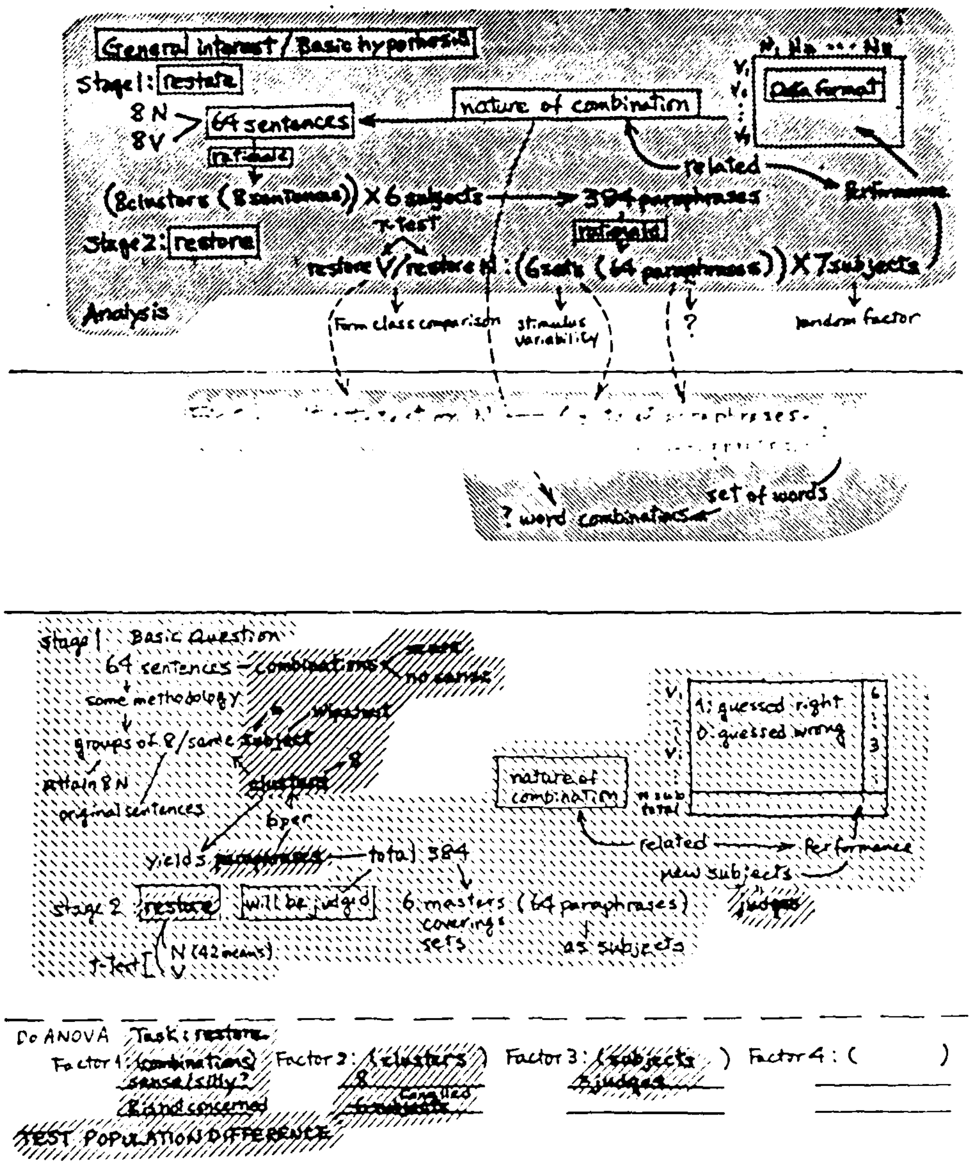

Figure 6. "Word combinations": Third occasion.

Table 4

"Word combinations": Third occasion
(R stands for researcher; S for statistician.)

475:	R:	well you could do an analysis of variance
476:		looking at
477:		breaking down a little finer
478:		because we have
479:		this structure that we are now representing we just
480:		do the t-test such as there are already six
481:		sets and there´s the same six sets here (tap tap)
482:		these people are judging
483:		set one and this group is judging the same
484:		paraphrases as one of these groups´ doing
485:	S:	huh
486:	R:	uh and uh
487:		there´s also
488:		the word combinations
489:	S:	uh huh
490:	R:	when they are doing they are they are judging
491:		the same
492:		they are judging the same set of words so you
493:		ought to be able to show
494:		let´s see now what was this

proper place to put that concept and gets easily distracted.

The diagram I used to depict the experiment hints why this was the case. The concept of word combinations just does not have a proper place in it if I try to keep its structure. If I assume that this diagram faithfully represents the researcher's schema structure, I can equate my difficulty of adding the concept in it with her difficulty to incorporate that concept into her schema. For me, it is difficult because 1) word combinations from eight nouns and eight verbs are on the upper left corner of the diagram, whereas the analysis design is mainly drawn on the right bottom corner (they are distant from each other in space), and 2) what is talked about as a candidate for a new factor is not the word combination itself but its properties, which do not have a proper slot in this diagramming yet. Likewise, it can be assumed that R had difficulty because R's main concern here is on the design for analysis, whereas the nature of word combinations has been thought out only in relation to the data format.

S's acknowledgement indicates that even after she registered "R is not concerned" to her first factor ("combinations"), she did not completely discarded it. Rather, R's comment could work to maintain it as yet a candidate factor.

Fourth occasion. In Figure 7 and Table 5, R has still been working on the same problem, but this time she gets the same word, "combinations," from S and starts to see a new possibility. Note, however, that R still does not see the new analysis right away. She had to let S explain what is really possible.

It does not take R long to realize that she can incorporate this into ANOVA design with her main interest of nouns versus verbs comparison. Now S can only suggest a simple t-test on word combination (line 580) while R sees the whole ANOVA possibility (lines 603-606): In S's schema for analysis design, ANOVA was expected but never made explicit. Another statistical tool, a t-test, has been introduced and registered. As the sketch suggests, I can assume that S is working on the t-test schema rather than on the ANOVA schema.

For R to come up with an ANOVA design, I have to assume that R has had a vast perspective, covering almost the entire schema (see where the dashed arrows come from). In fact, for the nature of word combinations to work as a factor, it should be understood that newly grouped sixty-four stimulus paraphrases in each set for the restore task are paraphrases of each of the sixty-four original noun-verb combinations. Also it should be known that the nature of word combinations has some relationship with subjects' performance on the restore task. It might be possible to say that to change a schema it is necessary to have a comprehensive perspective of it.

Conditions for the change. The biggest question here is what made the change from Figure 6 to Figure 7 possible. The most noticeable difference between the top boxes of Figure 6 and Figure 7 is that in Figure 7, R has finished checking all the ANOVA possibilities she had on

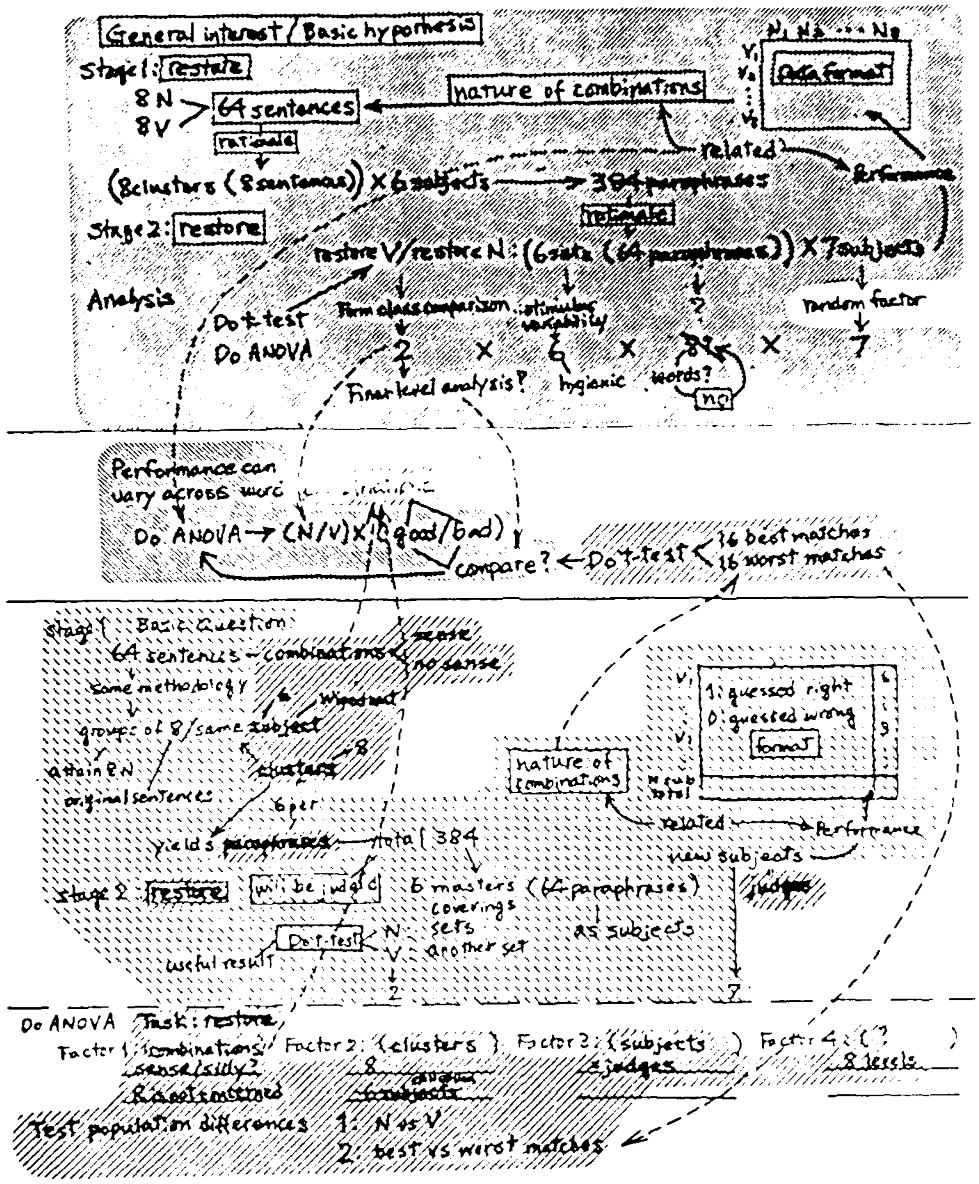

Figure 7. "Word combinations": Fourth occasion.

Table 5

"Word combinations": Fourth occasion
(R stands for researcher; S for statistician.)

560: R: now I´m not very interested in whether it varied
561: across the sets
562: that the sort of hygienic variable that you might not
563: mind knowing
564: but I´m much more interested in knowing
565: whether it varied across
566: uh
567: word
568: S: combinations
569: R: combinations right
570: I wonder if there is a way of doing that way
571: there´s
572: one
573: way
574: that one might do it
575: it´s to take sets of com-
576: sets of things one considers good
577: combinations
578: S: uh huh
579: R: and compare good versus bad
580: S: okay you could do a t-test on that alone
581: you wouldn´t even have to do that with ANOVA
582: R: you mean do that within
583: say
584: just within?
585: a word class ot across
586: S: okay what you could do is
587: you can take
588: a total score or
589: let´s say
590: judge the
591: I would guess that looks like this diagonal
592: which is diagonal which is darkened
593: are good word combinations
594: R: uh huh
595: S: so you could take
596: R: oh boy
597: R: you take th those
598: sixteen that you consider to be the best matches
599: take the sixteen that you consider to be the worst
matches

(Continues to next page.)

Table 5
(Continued.)

600:     get the total score
601:     and do the t-test on the total
602:     or do total score for best and total score for worst
603: R: here's another thing you could do
604:     you could do noun versus verb
605: S: uh huh
606: R: times good bad
607:     (pause)
608: S: okay
609: R: that might be a very nice
610: S: and
611: R: way of doing the analysis of variance
612: S: and do it that [illegible] ANOVA
613: R: yeah
614: S: okay

her starting schema. At that point, it is ready to change. This implies a high inertia of a starting schema; a schema guides one's thinking process but it also restricts one's focus.

Another point is that in Figure 6, R's "attention" was at "the sentences" whereas in Figure 7 it is at the extension directly from the form-class analysis in Figure 7. It could be said that R is "conceptually" closer to the original noun-verb combinations on Figure 7. For this closeness, or "focusing" in Grosz's terminology (Grosz, 1977), to have an effect on constructiveness, it has to be assumed that a schema has to be "looked at" at the fairly precise place where the change should occur.

S, on the other hand, has not changed her schemas very much. Her experimental schema has "registered" nothing new, only "acknowledged" some details about the proposed t-test on noun groups and verb groups. Her analysis schema has also been fairly stable, with only two substantive portions, i.e., word combinations as a possible factor for analysis and the use of a t-test. Her suggestion in Table 5 shows these two were actually her main concerns at this point.

In conclusion, for this particular case, for a change to occur it was necessary that 1) R had exhausted her starting schema and was ready to accept a new move and 2) S could inject a different emphasis (word combinations rather than sentences) which in turn could have been introduced by her starting schema. It is also important to note that R, even though she once explicitly rejected the word combinations as a factor (line 427), implicitly continued to give it supportive comments (lines 488, 538-540, 550-551), which encouraged S to maintain the concept in her schema.

2.4. Conclusions

These preliminary analyses already reveal several points.

1) In this particular interaction, starting with two different schemas helped the interaction to produce some constructive result. (S's design oriented approach helped her to focus on word combinations, in the first place.) If I assume that it is very rare that the two different persons share exactly the same (even very similar) schemas for a given topic, this suggests that any interaction done between two people can be potentially productive.

2) If there is a potential that any interaction between two different schemas can be constructive, it is interesting to see how much can be said about the precise conditions that make that potential a reality. There seem to be at least two conclusions I can draw from the above analyses.

2-1) It is suggested that the schemas the participants choose at the starting point of the interaction have a fairly high inertia. Before she could reach the final design, R had to come back to the "word combination" notion three times. For the inertia to be overcome, some repetitive pointing out seems to be necessary.

2-2) For an interaction to be constructive, a rather narrow range of focusing seems necessary. A person has to be focusing on the spot of the schema which should be modified.

The first point requires more research to determine how much accumulation is necessary to overcome the inertia. The latter also opens up a new question of how precise the focusing should be, as well as of defining the concept of focusing.

3) It was also suggested before one can change a schema one should have a comprehensive perspective on it.

4) The above analyses indicate that it is not necessary for the participants to share the same schemas to communicate. They were moving toward the mutual understanding, but even though I used R´s knowledge structure to draw upon what S gained, there was not a strong sign that S had ever reached the same structure. (The content sketches at the termination of the interaction do not differ very much from what are seen in Figure 7.) More interestingly, they could communicate and "constructively" interact, at least to the extent we saw in this case, based on these two rather different schemas. A simplistic theory of interaction might say that any successful interaction should be a construction of a common representation in two (or more) participants, but my case suggests that this is not necessarily a basic assumption.

3: THE LEVELS OF UNDERSTANDING AND POINT OF VIEW

Abstract

When people try to understand a mundane yet complex physical device such as a sewing machine, they proceed in an iterative fashion. Each point of "understanding" can be proven to be incomplete and thus to require a new level of understanding.

I asked several pairs of people to figure out how a sewing machine works while I videotaped and recorded the conversations. I observed an iterative search for understanding the functions and mechanisms of the machine and its subparts. In addition, the conceptual point in space from which the speaker appeared to be viewing the machine turned out to be important. This conceptual point of view (C-POV) was reflected in their use of language. The C-POV appeared to be stable during points of "understanding" and to shift frequently when they were in a non-understanding points.

In this paper I provide a framework for the study of how people come to understand physical devices such as sewing machines. Changes in C-POV can be regarded as a mechanism to promote the process of understanding.

3.1. Introduction

When we try to understand something, we often experience that the more we know, the more we realize that we do not know. What is the nature of this iterative process of understanding? How do we come to not understanding after understanding something?

In my studies, I asked several pairs of people to figure out how a sewing machine works while I videotaped and recorded the conversations. The task was extremely difficult, even in cases where one of the people started with the claim to understand the machine fairly well. Moreover, during the conversations, a number of points of "understanding" were reached, only to be proved wrong later on. The iterative process of understanding was observable in their protocols.

One important aspect of the performance associated with this was the location of the conceptual point in space from which the speaker appeared to be viewing the machine. This conceptual point of view (C-POV) was reflected in their use of language and was found to be stable during points of "understanding" and to shift frequently when the subjects felt that they were not understanding. I developed a framework to capture the nature of this cycling of understanding and non understanding. By connecting my observation to the framework, I was able to test speculation about the role of C-POV shift on the process of understanding.

Point of view has been relevant for students of problem solving for some time. Early researchers called this the problem of "set." When an object is seen in one way, it is very difficult for the same object to be seen from "a different perspective." Thus, in a problem where subjects were asked to put up a candle on the wall using only the given objects which included a candle, matches, and some tacks in a box, subjects experienced difficulty in finding a proper solution (which is to use the box of tacks as a platform for the candle), because when viewed normally, a box tends to appear as a "container" rather than a possible support (Duncker, 1945).

Recently, some researchers use the term "mental models" to describe a related issue. Whether the subjects think of an electric circuit as "flowing waters" or as "teeming crowds" affects their understanding (Gentner, Gentner, & Collins, 1982). While answering questions about how a heat exchanger works, subjects show evidence for having multiple and fragmental models based on their known facts, sometimes jumping among different models (Williams, Hollan, and Stevens, 1982). They suggest that the understanding could be promoted by revealing to the subjects the inconsistencies among different models. These results imply that looking at a thing from different points of view is a promising condition for progressing understanding.

Hutchins and Levin (1981) report that they could reliably identify their subjects' point of view while they were trying to solve the classic missionary and cannibals river-crossing problem. They observed that 1) people tend to make more errors on the bank where their point of view is not currently on, and 2) when they get stuck and then find a solution, this is usually associated with a change in the point of view. From these observations, Hutchins and Levin propose that point of view is related to what is most "activated" (i.e., salient) in the process of solving problems.

Hutchins and Levin's proposal suggests that the issue of point of view in problem solving is related to that of "focus." The recent work on discourse processes shows that the topic matter of the discourse can have hierarchically organized focuses (Grosz, 1977; Reichman, 1978). While a topic is discussed, its focus can be shifted. The thing being focused becomes the new topic, and affects the way things are described. Changing the focus (i.e., shifting the points of view) creates a hierarchy.

In this research I combine the notion of hierarchy of focuses and the effect of point of view. Because of the large amount of data and analyses that were involved, I have only been able to examine a small set of subjects, on a single topic. The greatest part of the work involves development of a framework for understanding, its coding scheme, and a coding scheme for point of view. The complexity behind the apparently simple observation is enormous. However, the approach and the results appear to have general implications.

3.2. Method

3.2.1. The task: The sewing machine stitch problem

To start, you will need to understand the sewing machine. [1] There are two different threads in a sewing machine: an upper one and a lower one. A stitch is made by pushing a loop of the upper thread through the material to the underside by means of the needle. The upper thread is then looped entirely around the lower thread. This, however, creates a topological puzzle, because in order for this to happen, the upper thread has to go around the free end of the lower thread, and how this could be done is not obvious. The answer lies in the bobbin upon

1. The type of the machine used here is a simple, electric powered one that can only do straight stitching. Technically it is a hook type, lock stitch sewing machine. I thank patent director Robert E. Smith at The Singer Company for providing nomenclature.

which the lower thread is wound. The upper thread can go around the whole bobbin. In other words, the bobbin itself serves as a free end. This process is depicted in Figure 8. When my subjects first recognized the function of the upper thread being looped around the bottom thread by means of the bobbin, they felt that they understood the machine.

There are still some problems, however. How can a bobbin serve as a free end when it must be also attached to the body of the machine? The statement "the upper thread can go around the whole bobbin" is a puzzle; to solve this puzzle you need some further understanding. Realizing that there is still another puzzle gives people a feeling that they do not understand the machine.

3.2.2. Subjects

I studied three pairs of subjects. The subjects were students and staff at the University of California San Diego, all of whom had been interested in the sewing machine stitch problem before I started this project. They participated on a voluntary basis.

Pair A consisted of a young faculty member (A1) who claimed to know the machine fairly well and a graduate student (A2) who did not. Because of their claimed knowledge, it was assumed that A1 would take a role of instructor and A2 would act as a student.

Pair B consisted of a research associate (B1), who was a seamstress and another young faculty member (B2), who was knowledgeable in physics in general but did not sew. However, B1 did not claim that she knew the mechanisms of the sewing machine stitch. It was hoped that this pair would represent a more corroborative instance.

Pair C consisted of two undergraduate students, one working as a psychology lab assistant (C1), the other doing her honor's thesis in the laboratory (C2). C1 had been working with the author as a research assistant, and had helped transcribe and view video tapes of interactions of pairs A and B. After this much experience, C1 thought she could explain the sewing machine to C2, though C1 still felt unsure of her understanding. C2 had more experience in actual sewing than C1.

3.2.3. Observational setting

The situation was set up to allow the pairs to interact in a natural manner, except that they were being video- and audio-taped. The author was present to operate the video camera. Subjects were instructed to "talk together to figure out how a sewing machine makes its stitches." No time limit was set.

There were three sessions. In the first session (Session I) all the pairs were provided with only paper and pens as problem solving aids. In addition, pair A used cords of their microphones to mimic the threads. Pairs B and C were provided with pieces of yarn. Occasionally a sheet of paper was used to mimic the fabric; a pen or its cap served as the bobbin. Session I lasted about 25 minutes for A, 35 minutes for

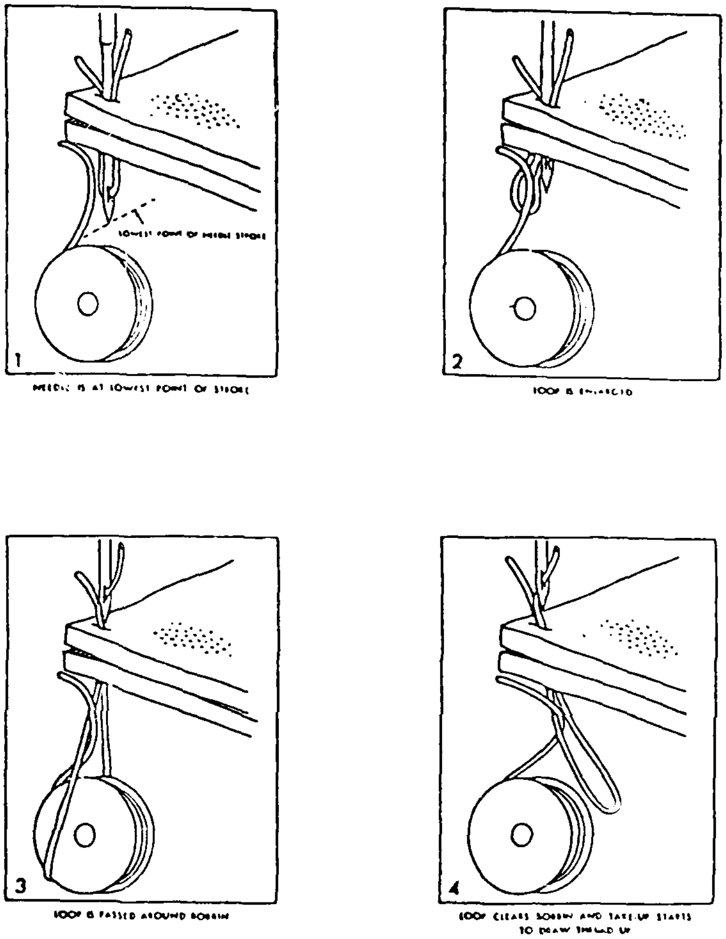

Figure 8. The process of making a stitch by a sewing machine. The figures are from Hannan (1975), used with permission.

B, and 20 minutes for C.

In Session II, pairs A and C looked at an actual machine, but without any thread on it. (Pair B did not get this condition, because the experimenter feared that they would become overtired after the long first session. There was no break between Sessions I and II.) During this session, they went back and forth between machine observation and the paper-and-pen, and the yarn mode. This session lasted about 15 minutes for A and about 10 minutes for C.

In Session III, a threaded machine was provided for observation. The subjects could go back to either the paper-and-pen or the yarn mode at will. They were allowed to take the machine apart. There was a two hour break between session II and III for pair A. This was because of equipment failure. There was no such break for pairs B and C. Session III lasted some 25 minutes for pair A and 30 minutes for pairs B and C. This figure includes time to operate the machine and to take it apart.

For subjects A2 and C2, a presession was run to get information regarding how much they knew about the sewing machine stitch problem prior to the interaction. (For the other subjects, it was hoped that this information would be revealed in their explanations during the first sessions.)

After the interaction, each subject was asked to come back and watch the tapes with the experimenter to help clarify (for the experimenter) their actions and statements. The information gained from these extra sessions provided much support for interpreting the protocols.

3.2.4. The data

Verbal protocols taken from the subjects' conversational interactions are the data for this research. Table 6 shows a typical excerpt from such a protocol. Lines were broken whenever the transcriber noticed breaks in utterances, so lines correspond roughly to breaths. Lines are numbered from the beginning to the end, thus line numbers serve as a rough estimate of time course of the interaction.

3.2.5. Intervention by the experimenter

The experimenter was present during all sessions. This gave her chances for direct observation as well as intervention. Intervening, however, was allowed for two conditions only. First, she could ask questions to clarify what was happening. The excerpt in Table 7 illustrates this type of intervention. Second, she could intervene when the interaction appeared to have come to a premature halt, either when both subjects agreed on a potentially problematic solution, or when both said they were stuck.

Premature halting took place twice. Once, a simple suggestion to restate the conclusion again was sufficient to draw the subjects' attention to the difficulties. For the other, the experimenter had to

Table 6

Example excerpt

302 A1: what actually happens is that the bobbin is in a little cage
303 and the loop gets shoved down
304 and the cage
305 takes
306 grabs onto that loop and
307 flips it over the bobbin
308 A2: hum
309 A1: like this
310 and then pulls up
311 see you flip that
312 this
313 thread over the bobbin
314 and then if you pull up on that thread
315 as the needle comes back up
316 it pulls up
317 and that
318 the loop then
319 is gonna
320 slip back up here
321 and eventually will grab on here so

Table 7

Example of the experimenter intervention
(E stands for the experimenter.)

259	A1:	this forms a collar
260		that holds this
261		but there is actually some space behind it
262		(pause)
263	A2:	uhhh
264	E:	would you please
265		A1, would you please point the
266		the the
267	A1:	on the sewing machine here
268	E:	I mean
269	A1:	what
270	E:	behind
271		which "behind" did you mean

ask more specific questions.

Subjects usually got stuck at the end of sessions I and II. Consequently, the intervention in these cases were suggestions to change the sessions. On one occasion near the end of pair C, Session III, being sufficiently sure that the subjects were not going anywhere, the experimenter suggested a new way to take the machine apart.

3.3. A framework for understanding processes

3.3.1. Function-mechanism hierarchy

To capture the iterative processes of understanding in these protocols, I propose a framework called "the function-mechanism hierarchy." It has several levels which are intended to correspond to psychological "levels" of understanding. Each level has a different specification of the "function" and of the "mechanism." The term "mechanism" here means a set of functions connected together with some simple relationships among them.[2] A "function" means an input-output relation to do something: a functional black box.

There will be a dovetailing of function and mechanisms: the function at one level requires the mechanisms of the next to explain it. Figure 9 illustrates this dovetailing schematically. To see this in terms of the sewing machine stitch problem, consider how a sewing machine accomplishes its function of making stitches (this is its level 0 function). One answer is that it has a mechanism (a "level 1" mechanism) that has as its function the crossing-over of the two pieces of thread. For some purposes, the explanation at this level would be satisfactory. But this level of answer does not explain that "crossing over." How is this done? To explain this, we need another level. The function of "crossing over" is accomplished by a mechanism that makes the bottom thread go through the loop of the upper thread. Again, this is a satisfactory answer for some purposes, but it does not explain the mechanism by which the function "going through" gets done. To do that, we must introduce a new level, which in turn will have its unexplained functions.

Figure 10 shows one possible function-mechanism hierarchy for how a stitch is made by a sewing machine.[3] It has six levels (including level 0), each of which represents a conceptually different "level" of

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2. A "mechanism" in this paper does not mean a piece of hardware, unless otherwise specified.

3. The nomenclature used in this paper for parts of the bobbin mechanism is given in Appendix 5.

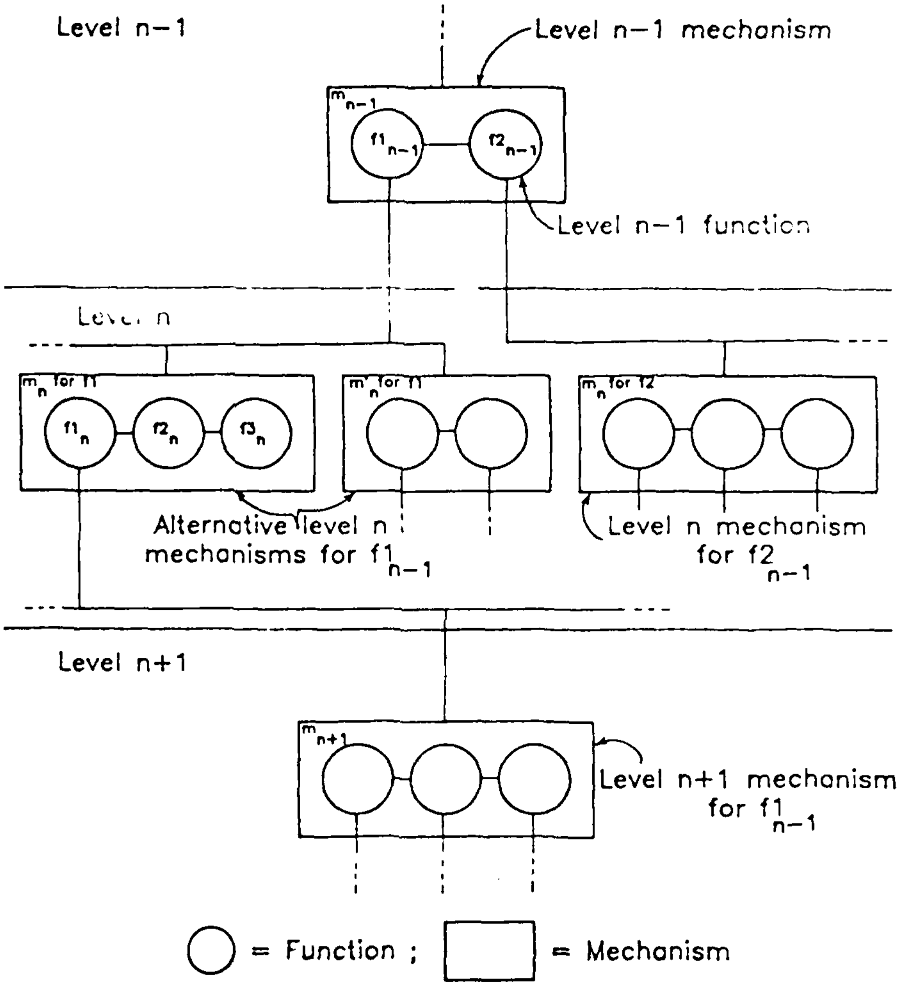

Figure 9. Schematic illustration of function-mechanism hierarchy.

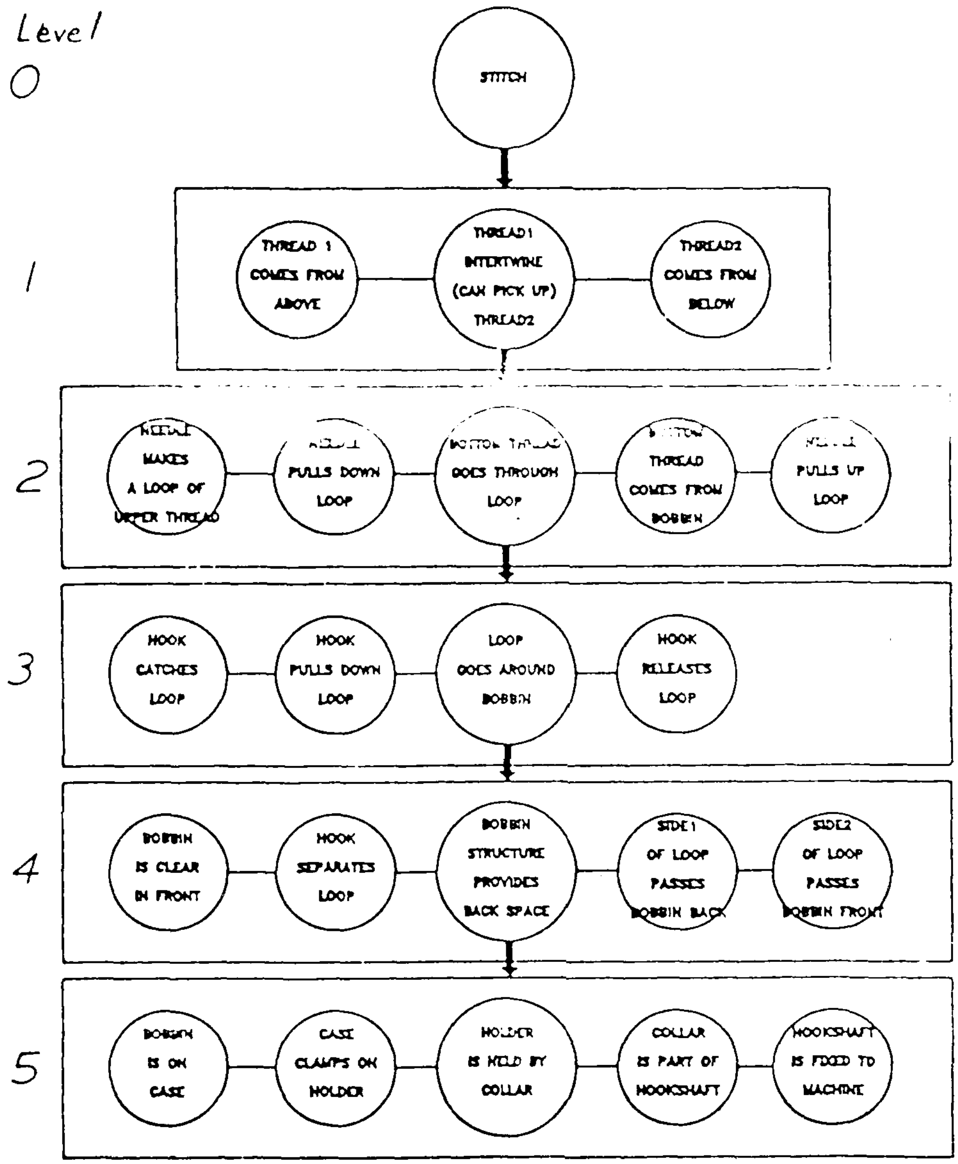

Figure 10. A function-mechanism hierarchy for the sewing machine stitch problem. The functions are in circles. The rectangles indicate mechanisms, in which several functions are connected together. The relationship assumed is a simple sequential order of occurrence.

the problem. On level 1, the main concern is with the physical objects involved in a stitch, rather than what is involved in "creating" such a stitch.

On level 2, the concern shifts to the exact topology of the sewed stitch. Do the threads cross over, or is there some other type of interaction between two loops (because there is no free end)? After the topology is determined to be of a crossing over type, the question now is what might actually be physically involved to create such a topology. This is yet another level of conceptualization of the problem, thus, level 3.

Level 3 introduces the bobbin to serve an important role in solving the sewing machine stitch problem. Yet on level 3, the bobbin and its all surrounding mechanisms are regarded as serving just one function, namely, providing a free end. On level 4, the actual path of the upper loop comes into focus, thus conceptually shifting the role of the bobbin from a free-end provider to a provider of a space in the back. Lastly, the physical configuration of bobbin parts comes into focus at level 5. The aim here is not just to specify the bobbin parts, but to integrate the functions of those subparts with the movement of the thread to achieve upper level functions.

The distinction of levels here is not meant to be absolute. I can not justify this particular gradation against other possibilities. Obviously, there could be more intermediate levels or sublevels on each of the above five levels. Level 1, for example, can be divided into two, one level focusing on the types of stitches (hand sewing simulation, chain stitch, or lock stitch), the other worrying about the actual topology of a lock stitch. There could be two sublevels on level 3, one just understanding the involvement of the bobbin mechanism (e.g., the hook on the bobbin holder twists the loop so that the loop somehow comes out around the bobbin thread, either clearing the backside of the bobbin or not), the other realizing the loop physically goes around the whole bobbin. I use five levels simply because that is all that are required to account by the data.

3.3.2. The hierarchy and feelings of understanding/non-understanding

I propose that the process of understanding follows the function-mechanism hierarchy as a framework. Each level can contain the same set of "steps" to be followed for understanding to proceed, which are explained below.

When a function in a level n mechanism is "identified" and "questioned" as an interesting problem, (i.e., one puzzles over how that function gets done) that opens up the next step of "searching" level n+1 mechanisms. Then a mechanism is "proposed" as a tentative solution. This proposal is "criticized," and if it passes this criticism, it is stated as "confirmed." There are cases in which the criticism contradicts the proposed solution. This leads to another search and proposal, which if not successful, can lead to abandonment of the problem as "impossible." After a mechanism is confirmed as an explanation for the function at level n, the mechanism at level n+1 can then be decomposed into its sub-functions, and one of those functions can then be posed as a further problem.

I call the transition between these steps "moves." Figure 11 depicts how these steps correspond to moves[4] between functions and mechanisms in the same format used in Figure 10.

I assume that when people are engaged in the steps of "identify," "propose," and "confirm," they think they understand the phenomenon at hand. It is only when they are on steps "search," "criticize," and "question" that they believe they do not understand. Roughly, when one finds an explanation in level n+1 mechanism for a level n function, it is felt to be understood; when a function of level n is questioned and its mechanisms are searched, this gives a sense of non-understanding. Thus, going through the steps and going down the levels produces an alternation of feelings of understanding and non-understanding. In summary, the following listing explains the relationship between levels, steps, and subjects' "state of mind."

Level	Step		State of mind
Function at level n-1:	Identified	...	Understanding
	Questioned	...	Non-understanding
Mechanism at level n :	Searched	...	Non-understanding
	Proposed	...	Understanding
	Criticized	...	Non-understanding
	Confirmed	...	Understanding
Function at level n :	Identified	...	Understanding
	Questioned	...	Non-understanding

3.3.3. Coding of levels of understanding

In order to identify whether an utterance reflected a state of understanding or non-understanding, utterances were categorized in terms of "levels" and "steps." This coding was done according to the function-mechanism hierarchy shown in Figure 10. First, each entire protocol was cut into units of minimum meaningful utterances. Among those utterance units, the ones that are relevant to the sewing machine stitch problem were picked out. Then they were categorized into functional classes according to the content they convey. Categories include "setting" (e.g., where a piece of thread comes from and where it

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4. It is in fact an arbitrary decision whether one refers to the proposed/searched/confirmed mechanism being on level n or n+1. I chose to put it on level n+1 because it requires a level n+1 function to be in it. The following specification may help the reader. A level n+1 mechanism satisfies a function at level n, while a level n function is required to form a level n mechanism as one of its components.

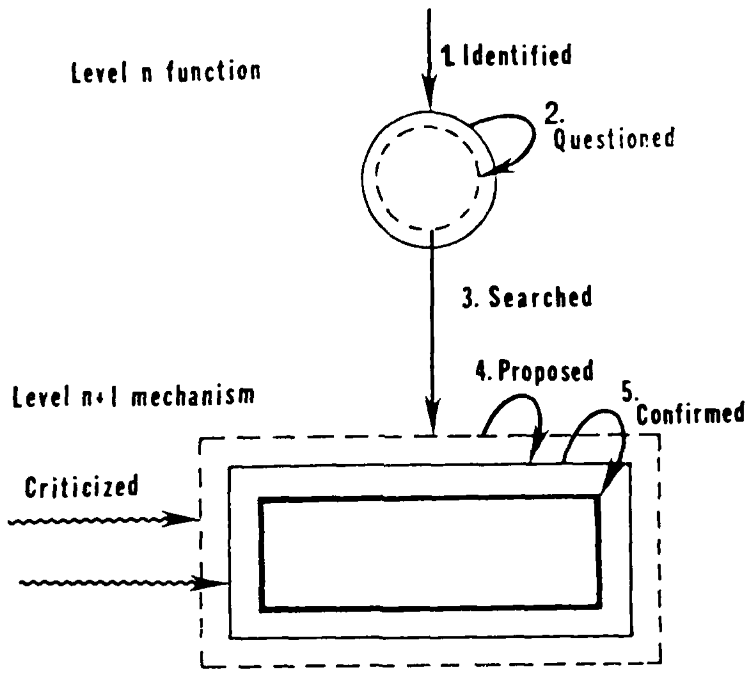


Figure 11. Standard moves and step names on a function-mechanism hierarchy. Circles represent functions, rectangles represent mechanisms. Arrows indicate possible moves, with the numbers denoting their standard order. Functions are drawn in solid lines when they are "identified" for further questioning, in dotted lines when "questioned." Mechanisms are in dotted lines when they are "searched," in thin solid lines when "proposed," and in thick lines when "confirmed." "Criticisms" are shown in zigzag lines.

goes to; whether the needle is up or down at a particular time), "process" (e.g., how the needle creates a loop out of the upper thread; how the upper thread loop goes around the bobbin), "result" (e.g., how the two threads interlock when they come out), "criticism," "question," and "judgment" (e.g., "I don't understand"). These categorized units then were grouped into higher order units. A "setting" plus a series of "processes" with a "result" make one such higher order unit for giving an explanation. Levels according to the function-mechanism hierarchy given in Figure 10 were assigned to these higher order units. Finally, steps of understanding process were determined for each such unit. How this analysis was done is given in detail in Appendix 3.

3.4. The conceptual points of view

When people talk about a physical device such as a sewing machine, their language allows us to infer from which point they are looking at the machine. These "points of view" are called "C-POV" (conceptual point of view), because the speakers need not physically move their bodies when they change point of view.

3.4.1. C-POV of a sewing machine

A sewing machine can be looked at from three different viewpoints. One can take an overall view or bird's eye view to see the whole machine. Then, one can consider the region of the machine where the stitches are formed from the top or from the bottom. The view from the bottom becomes important because most of the interesting things for the sewing machine stitch problem happen there. We call the point from which the person gets the overall view, C-POV G (G for global), the point the point from the top, C-POV LT (local top), and the one which gives the bottom view C-POV LB (local bottom).

When people worry about the topology of how the loop actually goes around the whole bobbin (to be more precise, how it can clear the back side of the bobbin), they can take sub C-POV's in C-POV LB. Here, the bobbin itself becomes the center of the entire view. This gives us C-POV LBt (small t for top), the point in front and above the bobbin and C-POV LBb (small b for back), a viewpoint at the back of the bobbin.

3.4.2. Coding of C-POV

Actual coding is done by a key phrase method. First, we assume that the speakers imagine the upright machine in front of them. This allows us to easily assign speakers' C-POV's to a number of phrases used repetitively in descriptions of sewing machine operations. The needle, for example, always "goes down" and "comes up" when viewed from the top and always "comes down" and "goes up" from the bottom. This ease of coding contrasts sharply with the complexity of coding experienced in other cases (for example, see Hutchins and Levin, 1981), where the same phrase can indicate different points of view depending on previous viewpoints.

One drawback of any key word method is that we cannot assign C-POV's where the key words do not occur. To cope with this problem, a second assumption was made. I assume that the speaker has a tendency to keep C-POV's constant rather than change them frequently and haphazardly. (There is indirect support for this in the sentence memory literature. See Black, Tunner, & Bower, 1979.) Based on this assumption it is plausible to infer that speakers keep their C-POV's until there occurs a clear indication of change that we can catch by our key word method. This gives an underestimated picture of changes but not an overestimation. For the purpose of this research, where the interest is in patterns of shifts in C-POV rather than its stability, the above method is safe because it gives the most conservative estimation of shifts.

I concentrated on two types of phrases as keys. One is with deictic verbs such as "go" and "come," the other is with deictic demonstratives such as "this" and "here." Key phrases were selected based on high frequency and native speakers' intuition. Table 8 illustrates the C-POV coding done on the excerpt in Table 6. Key phrases used for judgment are underlined. All the key phrases used are listed in the Appendix 4.

3.5. Results

3.5.1. The iterative process of understanding

In this section I describe how each individual "walked through" the function-mechanism hierarchy, and how they "iterated" the understanding-non-understanding cycle. Their courses of understanding are presented in diagrams. The figures in this section follow the notation introduced in Figure 11. Numbers on the lines indicate the sequence of occurrence of the moves. Two or more numbers on one line indicate that the same move occurred more than once, at times denoted by the numbers.

The hierarchy is abbreviated to include only the key subfunction in each mechanism. Whenever an individual came up with an "alternative" mechanism to the standard one, it is included to the right side of each individual's standard hierarchy. Each diagram contains two columns, one for each subject of the pair. Different sessions are depicted on separate diagrams.

First, I use the starting eight moves from pair A to illustrate how the diagrams are created and should be read. Then, I briefly talk

Table 8

C-POV coding on excerpt given in Table 6
(C-POV code : LT for local-top, LB for local-bottom.)

C-POV			
	302	A1:	what actually happens is that the bobbin is in a little cage
LT	303	A1:	and the loop gets shoved down
	304		and the cage
	305		takes
LT	306		grabs onto that loop and
	307		flips it over the bobbin
	308	A2:	hum
	309	A1:	like this
	310		and then pulls up
LT	311		see you flip that
LB	312		this
	313		thread over the bobbin
LT	314		and then if you pull up on that thread
LT	315		as the needle comes back up
	316		it pulls up
	317		and that
	318		the loop then
	319		is gonna
LT	320		slip back up here
LT	321		and eventually will grab on here so

about each session of each pair to give verbal descriptions of what actually happened. Last, I comment on general observations made on these diagrams.

Illustration: Pair A's first eight moves. Table 9 gives nine short excerpts, a) to i), from the beginning part of pair A interaction. Parts a) to i) of Figure 12 illustrate how diagrams present these interactive moves correspondingly. A2 opened up the interaction by explaining why he thought the machine could not work. In Figure 12 a), he gave this explanation by first giving a seemingly plausible (but not quite possible for him) level 2 mechanism, and quickly added he did not know how one of it subfunctions was possible (first A2 explained "what ought to happen is ..." and then, "however it seems impossible to me ..."). A1 started off his answer at level 2 (b: "the bobbin thread is actually passed through this loop"). This was a mismatch, because, A2's questioning of a level 2 function required a level 3 mechanism as a response, which satisfies the level 2 function. Therefore A2 tried to search a mechanism at level 3 on his own, which was expressed in a question form (c: "does it have a free end"), which turned out to be a "standard" search. "Standard" here refers to the function-mechanism hierarchy given in Figure 10. Anything other than those are called "alternatives." Because no alternatives given by the subjects were "correct" in terms of the actual machine, in this discussion, "standard," therefore, also means "correct."

From this, A1 appeared to have realized that A2 actually knew quite a bit more than expected, and so A1 responded by giving a level 3 mechanism (d: "the bobbin end is free ..."). A2 asked how it's subfunction was possible (e: "how [does] the bobbin itself work"). Trying to answer this, A1 found he did not know enough to give a satisfactory explanation. A1 wanted to propose another mechanism at level 4 (f: "there is a slot in [the cover] ... that grabs the loop"). He tried, but according to my coding scheme, what he ended up with was an alternative mechanism of level 3 quality. Moreover, this "proposal" was given in the language which falls into the category of "search" according to my coding (see Appendix 3). So, on the diagram, A1 "searched" an alternative mechanism at level 3, which differed from the standard hierarchy. A2 accepted this new move and followed the search (g: "is the needle coming through this slot?"). Meanwhile, A1 continued his search for a mechanism for the level 3 function and came up with a mechanism at level 4, which was again not on the standard path (h: "a little hook ... grabs the loop ... and forces it back over [the back space of the bobbin]"). A2 "criticized" A1's search at level 4, based on his understanding at level 2 (i: "[that would work] if the bobbin were ... floating"). Apparently A2 did not see the new mechanism as a solution.

In the rest of this section, you will find the figures for the entire course of understanding for each session for each pair. They were drawn in the fashion illustrated above. I will add some verbal descriptions and excerpts of what happened to accompany the figures.

Table 9

Excerpts for Pair A's first eight moves.

Figure	Excerpt
a)	A2: /and what seems like ought to happen ah is that you make a loop of thread down here/ and then you pull the bobbin thread through it/ ... /however it seems impossible to me to/ I mean you have the closed loop of thread coming down from above/ and you have a continuous string of thread along here/ and my problem is that ah you can't get this this piece of bobbin thread ah inside the loop/
b)	A1: /what actually happens is exactly what you've said/ it's a little bit more complicated than that I think/ but but the bobbin the thread that's on the bobbin is actually passed through this loop/
c)	A2: /uh do we have a continuous piece of thread down here/ or or is there does it have a a free end/
d)	A1: /ah it has a free end/ but the free end is a very surprising free end/ the bobbin end is free/ ... what actually happens is that the bobbin is in a little cage/ and the loop gets shoved down/ and the cage takes grabs onto that loop/ and flips it over the bobbin/
e)	A2: /okay uh that's all very nice if I can understand how the bobbin itself works/ ... how how is the bobbin supported/
f)	A1: /it sits in a little cage/ ... there is a cover (=cage on the drawing) that that fits over it/ now that sort of clamps on/ and there is a slot in this/ so the thread passes through/... there is the slot in there/ that grabs the loop/
g)	A2: /is the needle coming through this slot?/
h)	A1: /there is somehow there is a cover over this/ that has this slot in it/ and it grabs the loop/ there is a little hook/... where this spiral comes out/ and it grabs the loop/ and when the when the loop comes down/ it grabs the loop somehow/ and forces it back over here (=space between the back of the bobbin and the machine on the drawing)/ and so then I think the loop essentially you know sort of fits in like that/
i)	A2: /okay well that would all be very nice if the bobbin were really sort of floating in the middle of the bobbin case/

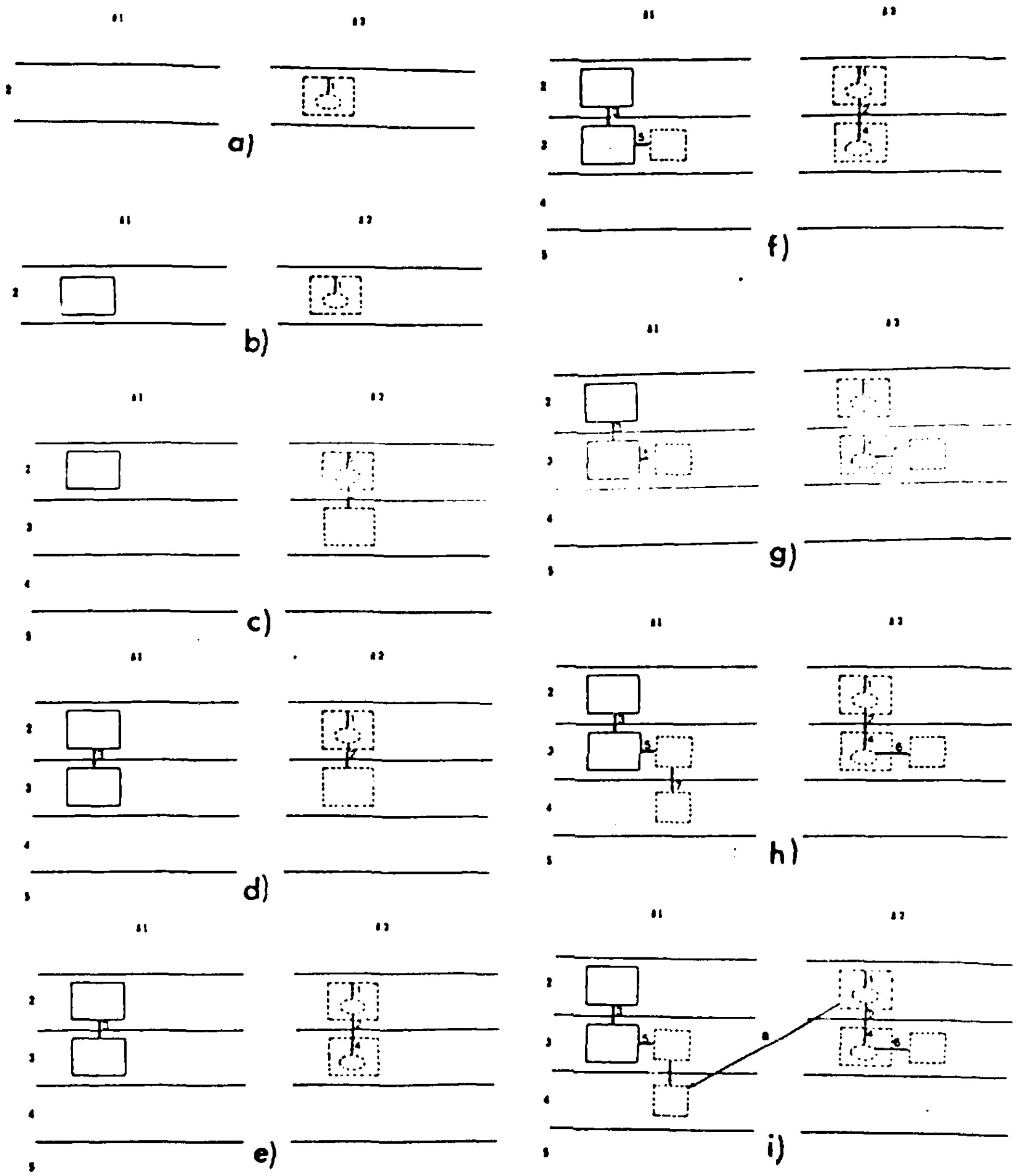


Figure 12. Pair A´s first eight moves. Each part of the figure has two columns, left for A1, and right for A2. Horizontal bars cut levels, with numbers on their left. Dotted ovals are "questioned" functions; solid rectangles are "proposed" mechanisms; dotted rectangles correspond to "searched" mechanisms. Arrows indicate moves, while zigzags denote "criticisms."

Pair A. Figure 13 gives a completed set of the diagrams for pair A. After their eighth move, A1 went through several trials of search on level 4 before he reached one non-standard solution (essentially the same one given in h in Table 9). A2 did not like this, kept criticizing and questioning. A2's repeated criticisms brought A1 back to level 3, let him to start asking (mainly of himself) questions about a level 4 function. Corresponding to move 22, A1 asked,

/and there is the whole question of/
which is not resolved here/...
/how this this thing is attached to the machine/

After this, he came up with a more standard version of level 4 mechanism, as well as a search trial at level 5. He expressed his search as (move 26),

/I mean that's that's attached to the machine somehow/...
/it's it's actually attached most part/...
/maybe there is more to this/ more two pieces or something/

All these moves, though, did not move A2 any further down from level 3. His last level 3 search, which corresponds to move 18, was stated as,

/it seems to get the loop on the (other) side/
you might have to go around one end or the other/

In Session II, looking at an unthreaded machine helped both A1 and A2 to come up with their own solutions, which each one proposed in turn. A1's solution, which was reached after clearing-up higher level mechanisms and functions (moves 28, 31, 34, 35, and 38), was very close to the actual mechanism. Actually he came to one standard proposal (move 52),

/.../there is no rigid atta-/
if this is just locked in here/

which he did not like (move 53),

/except for the problem/
that there is no easy way/
you could get a thread through these connection/
because everything is too tight/

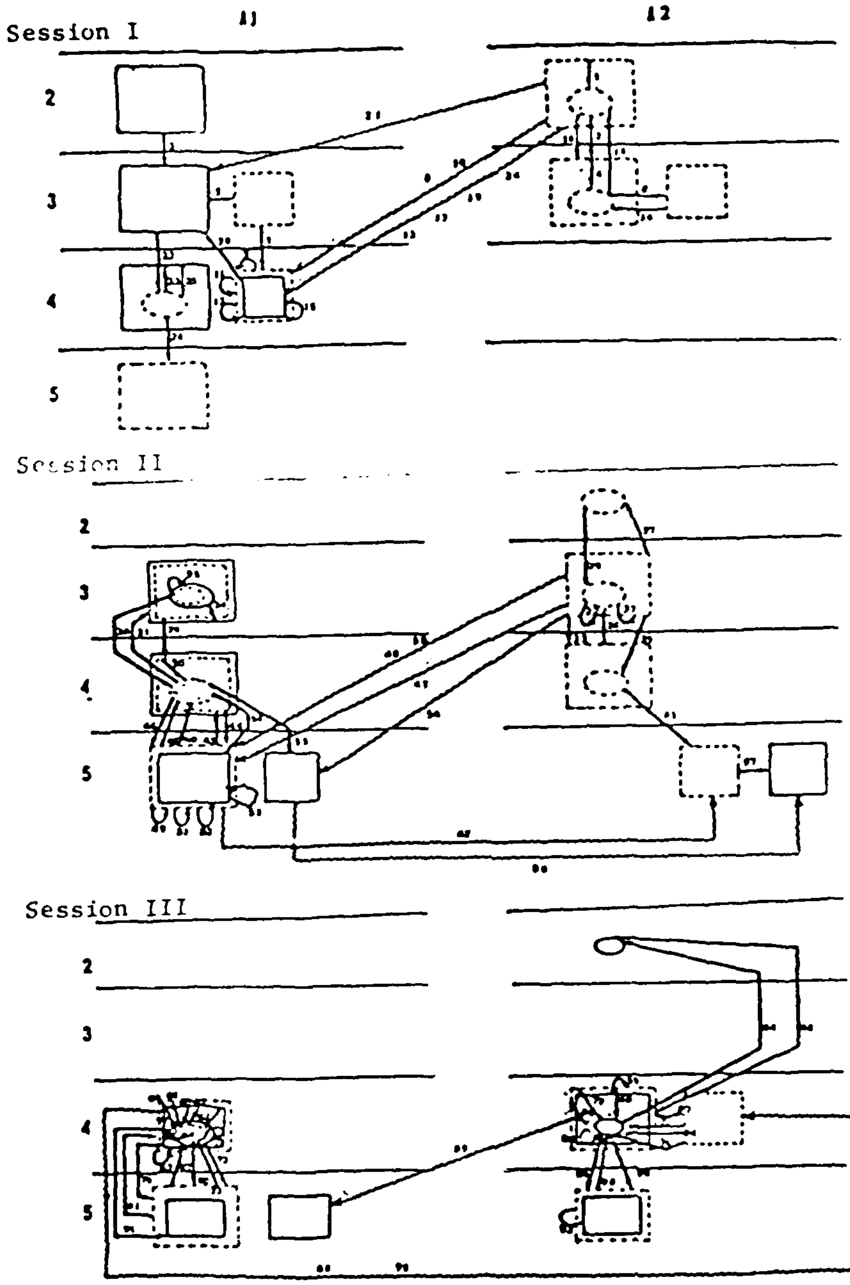


Figure 13. Course of understanding for Pair A. Functions are in ovals: When dotted, they are "questioned"; in solid lines, they are "identified." Mechanisms are in rectangles: When dotted, they are "searched"; in thin solid lines, they are "proposed"; in thick solid lines, they are "confirmed."

and changed it to an alternative with which he felt more comfortable. He proposed a ridge mechanism to hold the bobbin so that the bobbin can provide sufficient backspace for the loop to pass through. He stated this as (move 55),

/you can make more of a ridge here (i.e., between the back
 of the bobbin and its container)/
so the this would wouldn´t be tight/
this back here wouldn´t be tight against here/
if you made a little ridge here/

A2´s solution was more imaginative, which was to use a cum to push the bobbin up and down inside of its cage to make necessary space, but also hypothetically a possible one at level 5. In his own words this solution was stated as (move 41),

/maybe what it does is/
at at one one position/
uh maybe uh the bobbin is is somehow forced up against this side
 (top side of the bobbin holder)/
which is is keeping it steady/
and there is a gap between here (down side between the bobbin
 and the bobbin holder)/
and then it (the bobbin) continues to rotate/
uh this side (down side of the bobbin) can come down down here/
it´s it´s the wiggling part/
and now it (the loop) has room to get out up here/
so that would be a possible way for it for it to work/
uh that would make me happy/

Neither one, though, could convince the other.

In the third session, they continued the search for the level 5 mechanisms, which they found only after taking the machine apart. A2 made some regress to higher levels (move 64):

/there it is it´s really around the thread/
that´s amazing/

At one moment he thought that the loop had not gone around the bobbin after all, but some kind of twisting of the loop would have caused the same effect. This non-standard alternative is shown as a dotted rectangle on level 4 on the right side of the standard path. At move 74, he said,

/yeah I think it seems to me
the fact that it's making a twist in the loop/
that it's taking the sort of back side of the loop/.../
and twisting it around/
maybe is significant/

This possibility was dismissed by A1 immediately (the zigzag line numbered 68 and 78)

/that just tends to lock the stitch together a bit/

A1 reached the solution very close to the standard one stated in Figure 10 (move 91).

/that's that's space behind it/
that I was looking for/.../
see I think that's (the hookshaft is) grabbing it
(the bobbin holder)/
I think that that again I think this whole thing
(the bobbin holder) is just loose in here (in the hookshaft)/
held by the collar/

The final solution reached by A2 was stated in terms of an analogy with a spokeless bicycle wheel. A2 said (move 92),

/I've seen something which works sort of like this/
it's a spokeless bicycle wheel/.../
which is really amazing/
it's it's uh it has a collar around most of it/
except at the bottom/
where it's open/
and the tire is made of some hard kind of plastic/
and uh it's it's it has no center or spokes or anything/
it just runs around in the collar/

This was also an approximation of the standard solution.

Pair B. Their paths are shown in Figure 14. As soon as the interaction opened, B2 realized that there was no free end on two pieces of thread involved. This lead him to believe the topology of the interaction between those two thread must be some variation of a loop in another loop (move 5).

/we have basically that's from the top/
we have this loop through the material/

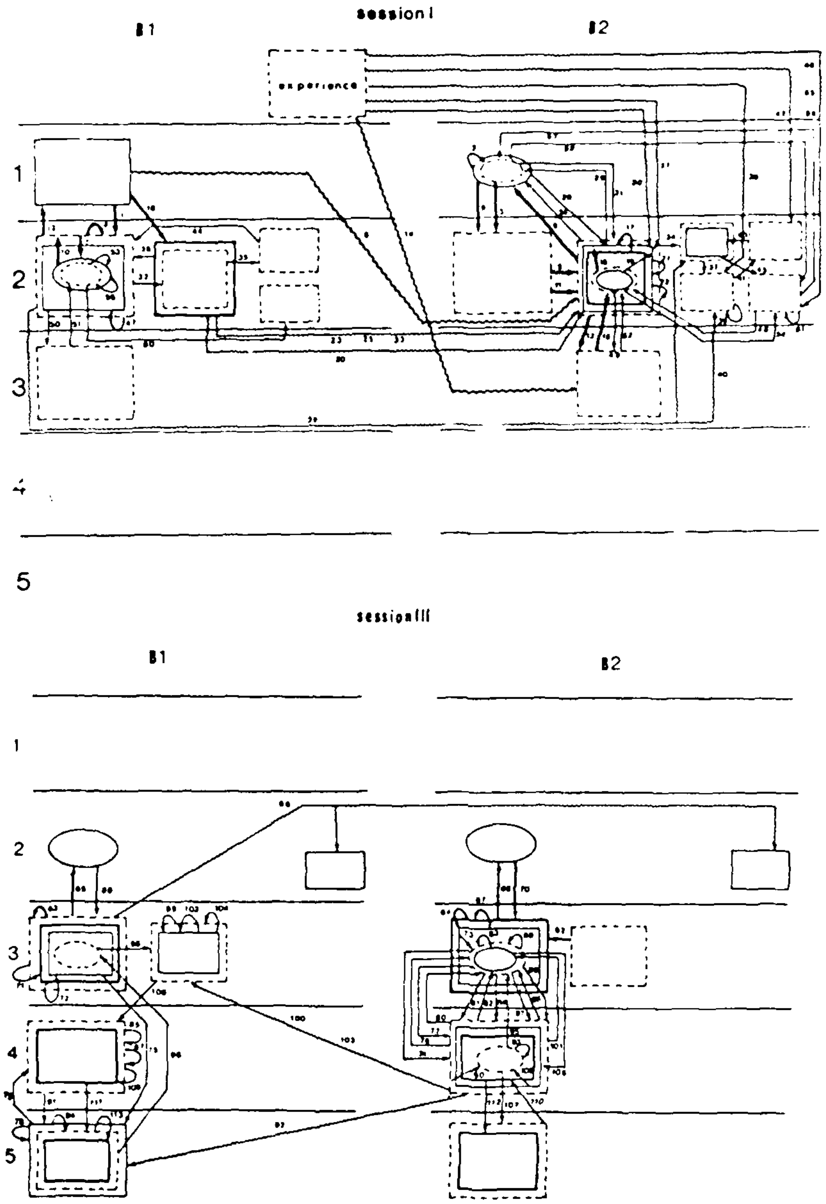


Figure 14. Course of understanding for Pair B. Functions are in ovals: When dotted, they are "questioned"; in solid lines, they are "identified." Mechanisms are in rectangles: When dotted, they are "searched"; in thin solid lines, they are "proposed"; in thick solid lines, they are "confirmed." Thick arrows and thin arrows are to distinguish moves before and after the experimenter interventions, respectively.

now suppose we could catch a loop of the other material
    (meant to be thread) inside there/...
and then get it pulled up/

Figure 15 illustrates this "loop in loop" formation in contrast with a regular lock stitch. B2 went even further to worry about a possible mechanism for this (move 13).

/you can imagine an arm certainly/
that would punch it through/
and then pull back real fast/
leaving the loop there/

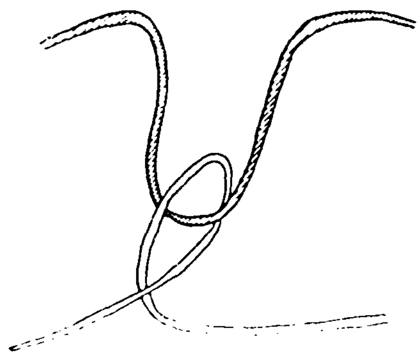
While B2 explained this verbally with some diagrams, B1 apparently thought this solution matched with hers. They stopped worrying about the stitch problem after move 18 and went off to talk about tension mechanisms. The experimenter asked them to restate "their shared conclusion," and B2's restatement made B1 notice that they could be talking about different mechanisms (moves 19 and 20).

B2: /I'm claiming they don't really interlock in the sense
        of crossing over/
    but it's a loop through a loop/
    so topologically they aren't really connected/
    but because of/
E: uhh/
B1: /alright, B2/

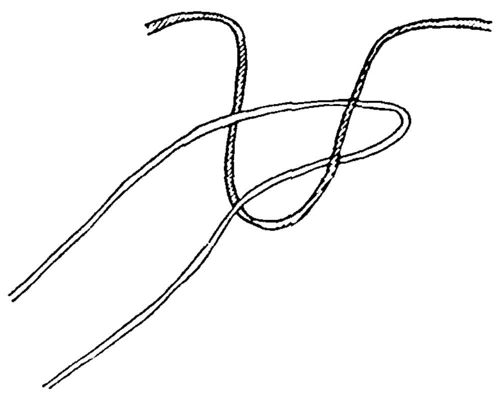
After this, B1 kept objecting to it from what she knew from her experiences of sewing (i.e., a stitch shouldn't come apart easily, shouldn't be as complex as a knot, there shouldn't be two dots for each stitch on one side of the fabric, etc.). Against these, B2 tried four more alternatives of this "loop in loop" solution at level 2, by making the interaction of loops harder to unravel, like twisting either the top or the bottom loop, knotting, or looping them twice. B1 tried one search at level 3, mainly from what she knew had to be happening, which was not solid enough to form any proposal.

They moved on to the threaded machine directly after the first session. There, B2 immediately saw the standard level 3 solution and could convince B1 of it (at move 70).

/slips it over the whole loop/
that's how it does it/
slips it over the whole shuttle
    or whatever that's called/



a) regular stitch



b) loop in loop

Figure 15. Constitution of stitches. A regular lock stitch (a) and the "loop in loop" version created by B2 (b).

They both thought they knew the answer and felt nothing was left for them to do in this experiment. At this point, the experimenter intervened to introduce a further question about level 3 function. She had to try four times to get her question through. In this sense, moves after this did not occur "naturally."

In search of downward level mechanisms, B1 at one point thought as A2 had, that the loop had not gone through the back side of the bobbin at all but instead some twisting could have caused the same effect (box on the right side on level 3, after move 97).

> /okay it (the hook on the hookshaft) catches it
>   (the loop)/
> and then twists it/.../
> I don´t think it it doesn´t go behind the shaft/...
> yeah that (one side of the loop) doesn´t that just
>   sort of stays there/
> and sort of floats over to the other side/

This was denied by B2, who did not deviate from the standard path very much.

Pair C. It was C1 who did most of the talking. Their paths are shown in Figure 16. She knew, from her viewing tapes of pairs A and B interactions, that "loop going around the bobbin" function had to play some important role in the solution (move 1).

> /I know it goes down the thread goes down from the needle/
> into the bottom part/
> where the bobbin is/
> okay um and where it makes that loop/
> that´s the confusing part/
> but I think it goes all the way around the bobbin/
> to catch that piece of thread/
> which comes out of the top/

Her problem was that she did not know how and where to integrate this piece of information. As a result, she spent a lot of time figuring out what the phrase could "mean" in terms of actual physical operation. She needed to go back to level 2 in the midst of Session I to clarify what the basic problem was (move 15).

> /that´s the stitch/
> the needle comes up through the cloth/
> and that makes the locking stitch/.../
> but the confusing part for me is/
> how this loop is going to grab this piece of thread here
>   (i.e., the bobbin thread)/

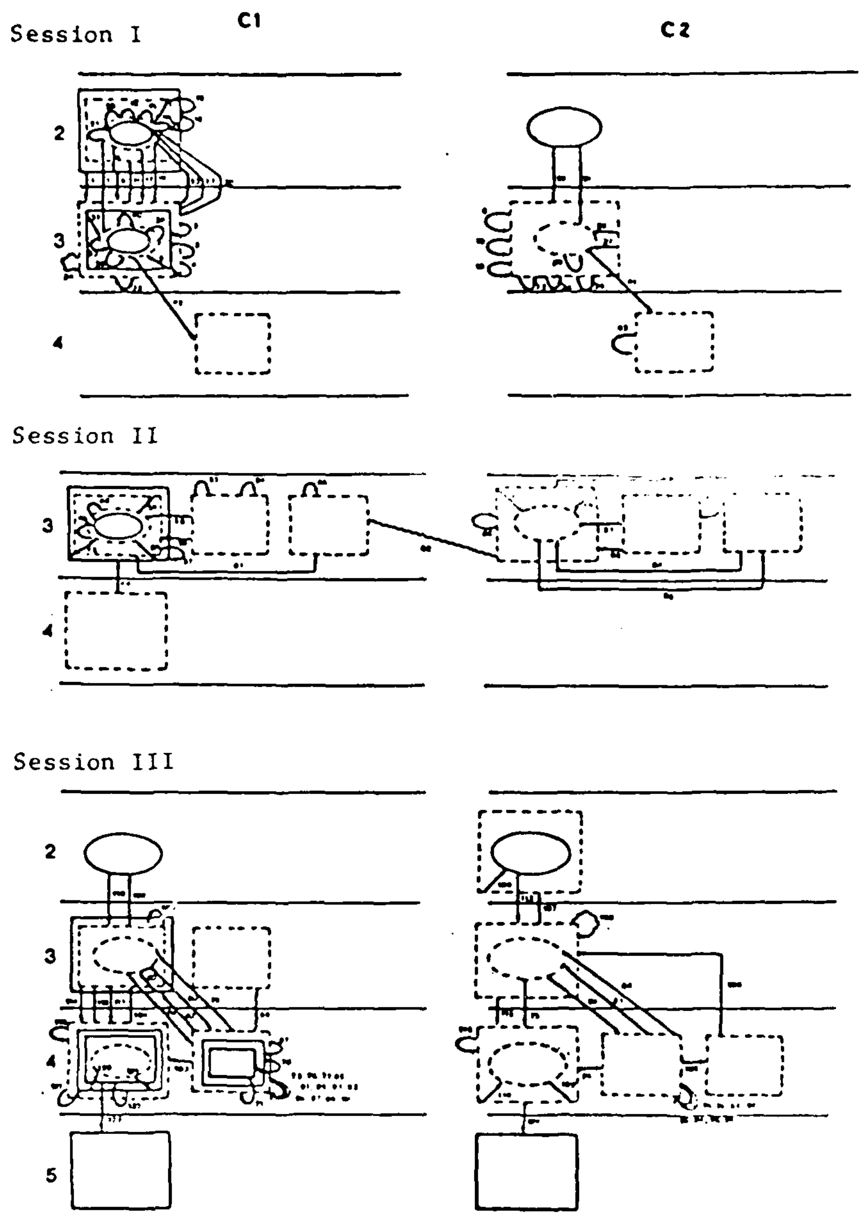


Figure 16. Course of understanding for Pair C. Functions are in ovals: When dotted, they are "questioned"; in solid lines, they are "identified." Mechanisms are in rectangles: When dotted, they are "searched"; in thin solid lines, they are "proposed"; in thick solid lines, they are "confirmed." Thin arrows at the last phase of Session III indicates that those moves occurred after the experimenter's intervention.

and bring it back out/

It was a relatively fast and straightforward path for C2 to follow C1 down to level 3. Her protocol indicates that she had some mechanism at level 4 at the end of this session, but it was nothing more than a search (move 41).

/this (the bobbin) is attached/
no/
well yeah I don't think there is a spindle there
(i.e., in the back of the bobbin)/

In Session II, Pair C immediately got stuck on an illusory appearance of an unthreaded machine. They thought the bobbin must have been attached to the machine both on its front and back, which, when taken together as the known "loop goes around the whole bobbin" function, gave them a double thickness of thread going around the whole circumference of the bobbin, clearing neither the front nor the back side of the bobbin. (See Figure 17.)

In Session III, after operating the threaded machine, they saw that there was no obstacle on the front side of the bobbin. This saved them from the double loop. This however lead them to an alternative on level 4, which was as yet another version of "twisting" solution (move 73).

/and it (the loop) crosses over/
so that one one (side of the loop) is going around/
while the other/
/.../
and while that one (side of the loop) stays behind/
this one (side of the loop) comes in front/

After a 30 minute struggle, they started to see the fundamental problem of the "twist" solution and made a move toward level 4 mechanisms on their own. By this time their interaction was quite lengthy. Moreover, it was clear that they did not have the prior knowledge like A1's to push them further than where they were. Around this point, the experimenter intervened and showed a new way to take the machine apart (i.e., to take the whole bottom panel off), which led them down to the standard level 5 mechanism.

<u>General observation about the courses of understanding</u>. In general, the subjects appeared to have followed the hierarchy. "Skipping" even one level is very rare. This is true for both downward moves and upward moves. There is a lot of going up and down between adjacent levels. This provides some empirical justification for the

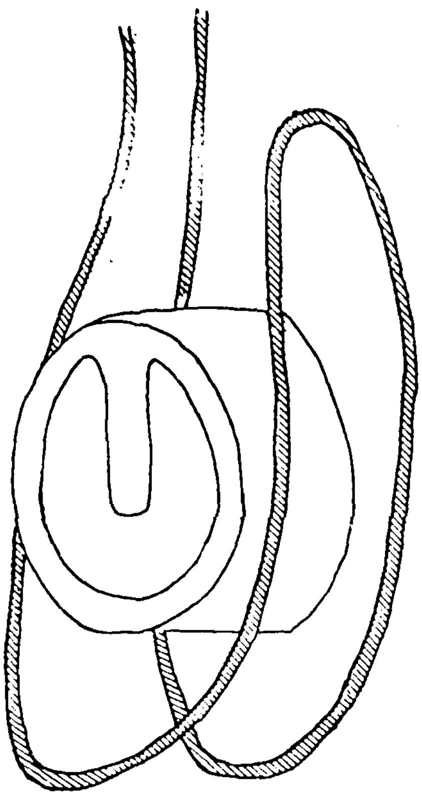


Figure 17. The double loop around the bobbin created by pair C.

hierarchy I am proposing.

All movements between levels, however, do not entail the iteration of understanding and non-understanding. For example, in Figure 12 d), when A2 went down from level 2 to level 3, he did so in response to A1's move. This did not involve any non-understanding on level 2 on A1's part. It is expected that people experience the understanding non-understanding iteration when they follow the path like the standard one given in Figure 11.

It is helpful to see what kind of moves do and do not occur in terms of the observed frequencies. Table 10 presents these figures. When the understanding proceeds as I am proposing, I should expect large numbers for the following: Moves of the four F -> F should show the highest frequency when within one mechanism, because when an identified function becomes questioned within one level, the standard F -> F move occurs. This happened 18 times out of 24 F -> F moves. For F -> M moves, the ones that are "Downward (n to n+1)" should occur most frequently, because after a function is questioned, it is expected to open up searches for mechanisms one level down. This happened 41 times out of 63. For M -> F moves, the standard move is to identify a function in a known mechanism on the same level, thus, "Within one mechanism" must be the most frequent. It is (29 times out of 61), but "Upward (n to n-1)" is also high (26 times). For M -> M, the standard moves are from searching to proposing to confirming, and the highest frequency again is expected in "Within one mechanism" row. The number for this is 27 times out of 86, the highest, but "Downward" has 23 moves and "Between alternatives" has 23. Standard moves are always most popular, though some non-standard moves were also used nearly as frequently.

The occurrences of the strict standard paths depicted in Figure 11 (identifying a function on level n to questioning it, questioning a level n function to searching a level n+1 mechanism, etc.) sum up to 47, or 20.3 percent of the total of 232 moves. This seems to indicate that the iterative understanding process occurs with relatively high frequency.

While the downward move from a function to a mechanism (Fn -> Mn+1) is a standard "search" path, the upward moves from a lower level mechanism to a higher level function (Mn -> Fn-1) can be interpreted as testing the new mechanism to see whether it satisfies the given higher level function. This could also be a necessary back-up when there is some failure. Though not a standard move, this is a reasonable move in terms of the function-mechanism hierarchy. This happened 26 times, suggesting this was actually as popular as standard moves for these subjects.

The subjects also liked moving between two mechanisms, either on one level (23 times) or between levels (downward, 23 times, upward 12 times). The coding system sometimes detected two different mechanisms talked about in one continuous fashion. Subjects, however, often appeared as if they did not even notice that they were talking about

Table 10

Types and the number of moves on function-mechanism hierarchy

	Type of move			
	F -> F	F -> M	M -> F	M -> M
Between levels				
Downward (n to n+1)	2	41 a	4 a	23 b
Upward (n to n-1)	4 c	0	26	13
Within level (n to n)				
Between alternatives	0	5	2	23
Within one mechanism	18	17	29	27
	----	----	----	----
Total	24	63	61	86

N.B. F -> F : Function to function
F -> M : Function to mechanism
M -> F : Mechanism to function
M -> M : Mechanism to mechanism

a) Each include one case of skipping two levels, n to n+2.
b) This includes two cases of skipping two levels, n to n+2.
c) This includes one case of skipping two levels, n to n-2.

different things.

When this happened within one level (n -> n), the high number of moves could have been an artifact of the coding scheme. It was after all my decision whether two mechanisms were different or the same. For example, when B2 gave five variations of his "loop in loop" stitch, I treated these as five different mechanisms, and as the consequence B2 "moved" 8 times among them. It could have been said that they were in principle all the same mechanism.

Between-level mechanism to mechanism moves are more problematic in this framework. Some 77 percent of them are interpretable. They happened at the points where subjects felt a need to confirm a one level up mechanism to secure what was known, or at the end of the interactions where they summarized their explanations. For the other 23 percent (8 times), however, subjects went down one level while they were searching for mechanisms (i.e., moves occurred between level n mechanism search and level n + 1 mechanism search). The above result suggests that for a considerable number of times, they went down through the levels without articulating any particular understanding. The protocols are product of communication and they do not always directly reflect the subjects' thinking process. Still, this non-articulation might mean that they actually went down levels without experiencing understanding. If this would be the case, it is a challenge for my proposal. How this could happen is an interesting issue for further research.

The frequent move between mechanisms on one level (Mn -> Mn) might appear to imply that people came up with two or more alternatives and compared them as their strategy. Their protocols, however, do not always support this. In f in Figure 12, for example, when A1 tried to go down from level 3 to level 4, but ended up giving an alternative on the same level. In fact, subjects rarely talked as if they were comparing alternatives. The only exception was B2, who gave five different versions of his "loop in loop" stitch. He contributed 12 instances (8 by himself, 4 more by having B1 respond to his suggestions) to the total of 23 within level mechanism to mechanism moves. This seems to imply it is indeed difficult to see the same thing from different perspectives.

3.5.2. Shifts of C-POV

Assuming that the analysis of the iterative nature of understanding is to a reasonable extent capturing the actual process, it is now useful to see how the pattern of C-POV shift is related to it. Compare excerpts a) and b) in Table 11: a) is one of A1's "search" for mechanisms at level 5; b) is his "proposal" for the same level mechanism. Notice that C-POV shifts much less in b), the "proposal," than in a), the "search." In the coding scheme, "proposal" is hypothesized to reflect an understanding state of the mind while "search" is a reflection of non-understanding. Together, excerpts in Table 11 suggest that A1 shifted his C-POV's more often when he felt he was not understanding.

Table 11

Excerpts for A1´s "search" and "proposal" at level 5

Excerpt a) : Level 5 Search

C-POV			
	592	A1:	there is no axle (through the bobbin)/
	593		that I´m sure of/
LT	594		and it (bobbin) is just floating in there/
	595	A2:	well/
	596	A1:	I mean it´s probably resting/
LB	597		you know it´s it´s probably physically resting in this/
	598		but
	599		there
LBb	600		somehow the thread is guided back here/
	601		uh
LBt	602		so I think it actually doesn´t go down to the place where it
	603		resting/ it´s
	604		guided back/ and then
	605		sort of slips up/
	606		but there is
	607		there is no
	608		there is nowhere
	609		sort of/
	610		oh it´s not
	611		becoming/
	612		there´s nowhere
	613		a physical connection
	614		that
	615		prevents
	616		topologically prevents
	617		the
	618		thread from passing over the bobbin/
	619		it is just sort of
LB	620		bouncing around loosely in this cage/
	621		yah [sighs]/
	622	A2:	we-ell [sighs]/

N.B. C-POV codes

LT : Local, top (top of the machine)
LB : Local, bottom (bottom of the machine)
LBt: Top of local, bottom (top of the bobbin)
LBb: Bottom of local, bottom (bottom of the bobbin)

Table 11 (Continued)

Excerpt b) : Level 5 Proposal

C-POV			
	764	A1:	because
	765		because you can imagine the loop/
	766	A2:	okay/
	767	A1:	here´s here´s the other loop
	768		on the upper thread
	769	A2:	right/
LB	770	A1:	coming down
	771		right?/
	772		and it´s like/ here
	773		here´s the loop right?/
	774		and now if I take
LB	775		one of these pieces/
	776		and sort of
	777		flip it
LB	778		over here/
	779		so
	780		it goes like this/
	781		so this is the thread/
	782	A2:	okay/
	783	A1:	then I can
	784		pull up on it/
LT	785		and now the other thread will be looped around there/
	785	A2:	ahhhh
	787		I don´t think so/

C-POV code LT : Local, top (top of the machine)
LB : Local, bottom (bottom of the machine)

To see how general the above observation is, Table 12 shows the ratio of "shifts" in C-POV for understanding and non understanding states. The ratio is taken by dividing the number of observed shifts by the number of maximum possible shifts for each occurrence of a step for each individual. Consider the excerpt a) in Table 11. In it, there are 12 utterance units uttered by A1 (slashes indicate boundaries of units).[5] This means that there are maximally 11 chances for C-POV's to shift. Four shifts actually occurred (LT to LB, LB to LBb, LBb to LBt, LBt to LB). The ratio thus is 4 divided by 11, which is .36.

From the table, the pattern of "less shifts with understanding, more shifts with non-understanding" is consistent. The difference is significant, $F(1, 5) = 37.32$, $p < .01$.

Table 13 shows the ratio of shifts in C-POV according to steps. "Searching mechanisms" and "questioning functions" show consistently high ratios of shift for all six subjects (except for the 1.00 for C2's questioned function, which is based on only one observation and appears to be accidental). These are steps where a function in a known mechanism (of level n) is now seen as problematic and mechanisms on one lower level (level n+1) are sought for to satisfy the function. Shifts in C-POV appear to occur at the point where a functional statement is reached, but its mechanism is not yet available. This suggests that C-POV shifting has something to do with the search for submechanisms hidden in a functional statement.

3.6. Conclusion

To understand a mechanical device means to be able to explain its function in terms of relationships among its subfunctions. This relationship is called a mechanism. When people can express this mechanism, they feel that they understand the device, and they can explain it from one stable point of view. However, there is no limit to the level of explanation. Having explained something at one level, there is always a further mechanism that needs to be determined. Thus, no matter what level the explanation is given at, people can go a step further by focusing upon one of the subfunctions of the explanation, seeing it as providing an entirely new question. At this point, the further detailed mechanism to accomplish that new function may not yet be known, which creates a sense of non-understanding. This cycle constitutes the iterative process of understanding.

For the understanding to proceed as I have proposed, two things must happen. One is that when a newly identified function poses a new question, its mechanism has to be searched and reached on a new level.

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5. Judgmental units ("that I'm sure of" and "yah") are not counted.

Table 12

Ratio of C-POV shift
for understanding and non-understanding states

State of mind	Ratio of shifts (Observed frequency/Possible frequency)					
	Pair A		Pair B		Pair C	
	A1	A2	B1	B2	C1	C2
Understanding						
Ratio	.17	.05	.15	.07	.09	.00
Frequency	17/102	1/19	15/101	6/87	9/101	0/2
Non understanding						
Ratio	.28	.14	.21	.26	.27	.14
Frequency	49/178	15/104	32/156	30/117	92/343	12/86

Table 13

Ratio of C-POV shift for steps

Step	Pair A		Pair B		Pair C	
	Ratio of shifts Observed frequency/Possible frequency					
	A1	A2	B1	B2	C1	C2
Function:						
Identified(U)						
Ratio	-	.00	.00	.00	.12	.00
Frequency	-	0/2	0/4	0/5	3/25	0/2
Questioned(NU)						
Ratio	.25	.14	.00	.30	.40	1.00
Frequency	1/4	2/14	0/1	3/10	18/45	1/1
Mechanism:						
Searched(NU)						
Ratio	.28	.16	.24	.25	.24	.13
Frequency	48/169	7/43	32/131	25/100	67/284	11/84
Proposed(U)						
Ratio	.18	.00	.15	.09	.07	-
Frequency	13/74	0/10	13/85	6/65	4/60	-
Critisized(NU)						
Ratio	.00	.13	.00	.29	.50	.00
Frequency	0/5	6/47	0/24	2/7	7/14	0/1
Confirmed(U)						
Ratio	.14	.14	.17	.00	.13	-
Frequency	4/28	1/7	2/12	0/14	2/16	-

U: Understanding
NU: Non-understanding

In the attempt to understand this new level, people can look at the function from various points of view, and this shift of view sometimes appears to be reflected in the language used to describe the phenomenon. In this sense, shifting of C-POV can play a positive role in promoting understanding, at least in a physical device such as a sewing machine. My data suggest that this is a plausible case. The shifts in C-POV appear to reflect shifts in conceptual views of the problem.

Another aspect of understanding is the realization that any mechanism can be decomposed into its subfunctions, thus one can ask about them further. This is also the place where shifting a point of view would be beneficial, because, after all, the "focus" has to be shifted to a subfunction from its surrounding mechanism. My protocols indicate that this could be a very difficult process. When pair B felt comfortable with their level 3 explanation, the experimenter had to intervene heavily to have them shift their focus to one of its subfunctions. Unfortunately, the type of C-POV I treated in this paper did not deal with this kind of focus shift. In fact, the process of how a function is identified was hardly visible in my protocols. A new technique has to be investigated for looking into this process.

There could be two reasons why I observed a stable C-POV while my subjects were understanding. One possibility is that in order to explain the function of a mechanical device in terms of its mechanism, one must have a coherent structure or model of the device. When subfunctions form a coherent "model" it becomes easy to talk about the model as a whole, as if one is looking at it from one point of view. This coherency of the "model" could facilitate the use of stable point of view in expressing operations associated with the model.

If this is the case, then one would predict that when experts talk about the sewing machine operation, they should be able to talk about it without shifting their C-POV's. I have not done this experiment, but I do have some support. Below is an excerpt from a letter from a patent director at The Singer Company. (Cited with permission.)

> A lock stitch is made by using two different threads, one of which is projected through the fabric and formed into a loop through which loop the entire supply of the second thread is passed. The entire supply of the second thread is usually wound on a bobbin.

There is no shift involved in this level 3 statement. Remember a level 3 explanation has to include the needle movement as well as the loop movement. This covers a wider scope of physical movement on the sewing machine than explanations on any other level. Consequently, level 3 can show a high ratio of C-POV shift. More interestingly, the author of this letter uses none of my key phrases to give this explanation. It is not that he uses "ordinary," C-POV associated language and still keeps his point of view constant. He seems to have an entirely different way of talking about the whole phenomenon from my subjects, namely, to talk about it from a very global point of view. It would be interesting to see how an expert behaves in a conversational situation.

There could be another reason for why people use stable points of view in giving explanations. Table 13 indicates that a stable point of view is particularly preferred when giving a proposal for possible solution. While one is trying to "search for" a solution, this process is mainly an individual endeavor. Once one is ready to "propose" his solution to the other, the aim is to communicate the solution to the other. In other words, "search" is more of an individual-oriented action, whereas "proposal" is more of a communicative action. (Or, the "search" is more of the self-oriented communication while the "proposal" is more oriented toward others.) Communication (more precisely, other-oriented communication) is a process of building a model of whatever is talked about: speakers try to build in their language a model of what they wish to convey; listeners try to build from the speakers' language a model of what is conveyed. We can speculate that when communicating, speakers are expected to give clues about the model they are talking about and thus help listeners to build their version of the model. The speaker's point of view is one such clue, possibly a very basic one. Using one stable point of view rather than shifting around is one possible way to make this conveyance easy for both the speaker and the listener.

There is in fact some work done on this line. Kuno and Kaburaki (1977) claim that there is a "syntactic" rule which bans intermixing conflicting points of view in one utterance. In a psychological experiment, these "rules" are shown to have effects on comprehending and memorizing sentences (Black, Tunner, & Bower, 1979).

Based on this line of argument, it is plausible that the more an utterance is directed toward communication, the more stable its point of view will be. This could be a shared meta-linguistic notion about language use, like Grician conversational postulates, which could have affected my subjects' way of saying things. This might explain why we did not see too strong a stabilizing effect on "criticism." By definition, it was categorized as "non-understanding," but its aim was to communicate complaints to the other participant. While "non-understanding" implies C-POV shifts, linguistic communication requires a stable point of view.

I do not want to claim that decomposition of a given function is the only role for shifting one's point of view. I do not want to claim either that the communicative force always works in the direction to stabilize the point of view. The C-POV shift seems to be one factor at work in searching processes. The communicative consideration is one force to stabilize speaker's point of view in utterances. However, even in the scope of the limited data dealt with in this paper, the shifts in C-POV appears to play an important role in our understanding. This topic deserves more attention.

4: ERROR DETECTION IN NATURAL CONVERSATIONS

Abstract

In the protocols of a two person conversation, an interesting pattern of error detection was identified. When the subjects were at a certain level of understanding, speech errors associated with prior levels were often not corrected; speech errors associated with that level were often corrected by the speakers; Errors associated with levels more advanced than their current one appeared neither to be noticed nor corrected.

4.1. Introduction

In the course of studies on natural dialogue I noted that speech errors were not always spotted by the participants. Speech errors are a reasonably frequent occurrence. A reasonably large amount of research has been conducted to determine the psychological and linguistic mechanisms that might be responsible for them. However, the correction and detection of errors has not been much studied. In this chapter I examine one aspect of the detection and correction of speech errors. The purpose is two-folded; one to seek a consistent pattern for speech error detection, the other to give some side support for the framework of understanding developed in Chapter 3.

If comprehension of natural conversation involves some amount of conceptually guided, expectation based processing, then knowledge about a topic should play an important role in the detection of errors. The following incident demonstrates this point.

Prof. N. sent a note to one of his graduate students, commenting on the student's research comparing typing differences of novices and experts. Part of N's note read: "...your study on differences between novices and beginners..." (rather than "novices and experts"). When the student read the note he spotted the error and returned the note to N asking him to correct the error. N re-read the note (several times) and was unable to discover the error. One other student decided to investigate this phenomenon and showed various members of the laboratory the note, asking them if they noted anything strange about it. The results of this informal survey indicated that the more familiar the reader of the note was with the work being discussed, the less likely they were to detect the error -- or if detected, the longer the latency to do so (Erickson, note 1).

This observation is the starting place for this research. The hypothesis under test is that the more people know about a topic the less likely they are to detect errors. Presumably this would be due to automatic processes occurring during the comprehension process that operate to make sense of the information received: even erroneous information sometimes can be so processed so as to be properly interpretable.

This hypothesis receives mild support from the literature. Norman (1981; Table 3) gives examples of speech errors that were not corrected or even noted by either speaker or listener, when conversing about mundane topics. Erickson and Matson (1981) showed that some errors were very difficult for their subjects to spot (this phenomenon is robust enough to make a good classroom exercise). Healy (1980) has shown that errors in function words are much more difficult to spot than other kinds of typographic errors.

The hypothesis is not easy to test, especially in naturalistic surroundings. Usually we do not have a good way to tell what people should and should not know. In this chapter, I report how one such observation was made possible. People correct errors most often when the errors are at the level of their understanding. People catch less errors when the errors belong to what is supposed to be known to them.

4.2. Method

4.2.1. Data

The same protocols as in Chapter 3 were used. The conversational situations, subjects, and procedures for collecting the protocols are thus the same as in Chapter 3.

4.2.2. Detection of errors

In order to identify an error, we must distinguish between the intention and the action (Norman, 1981). In this study, I tried to determine the intention of each uttered phrase and compare it with what was actually uttered: whenever these two aspects of a phrase do not match, it is said to be an error. Errors in this chapter are restricted to cases where the intended meaning was clear.

I defined "a corrected error" to be an error made, caught, and corrected, either by the speaker or the listener. For this class, I required immediate correction. When the correction was made by the speaker, the correction had to occur before the next sentence began. When the correction was made by the listener, they had to do so at the first chance (i.e., the first "turn" of conversation). All other errors are called "non-corrected" errors.

First, two readers carefully read the protocols to detect errors. Then, detected errors were confirmed with the original speakers in one of the post-interaction interviews. Thus the errors reported here are only those that the speakers themselves admitted as errors. For non-corrected errors, their intended meanings were also confirmed by the original speakers. There was a six month time lapse between their original interaction and this confirmation.[6]

There were eight cases where the apparent errors were not confirmed by the original speakers. Among these, six times the speakers thought they could have used the phrases to mean their intended

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6. This long time lapse is unfortunate, but I did not think of this analysis until several months after the observation had been completed.

meanings. For the other two cases, the speakers were not sure what they were trying to talk about. These cases are not counted in the data.

Corrected errors were easy to detect. It was much harder to detect non-corrected errors. I tried to use one of the original speakers as a detector. This was not very successful. Much as in the case of Prof. N., she failed to detect many of her errors, but when they were pointed out to her, she agreed they were indeed errors. I have not yet found any systematic/operational way to catch all the errors. Accordingly, I do not claim I have caught them all in this study.

4.2.3. Levels of understanding

Errors occur in contexts. In order to decide the understanding level of these context, the result of "levels of understanding" coding described in Chapter 3 was utilized. In order to distinguish what is known and what is not, the course of understanding in terms of these levels was examined for each pair (details in Chapter 3). The subjects' understanding proceeded mostly as proposed by the hierarchy. Thus, as a general rule, when they were on level n, levels n-i were known, while levels n+i were not fully understood.

4.2.4. Identification of levels for errors

For each error, levels can be independently assigned for its uttered phrase, its intended meaning, and its context. According to the hierarchy given in Figure 10 in Chapter 3, each "level" of understanding has its own associated phrases. "Stitch" belongs to level 0, while "back side of the bobbin" belongs to level 4. "Going around (the bobbin)" is a phrase most likely used for a level 3 explanation, while "going through (the back side of the bobbin)" is used for an explanation on level 4. Table 14 gives the list of corresponding phrases for each level. Levels of each uttered phrase and its intended meaning were decided according to this table. These levels were then compared to the level of their surrounding context (see previous section). For example, consider the error in the excerpt 1 in Table 15. Excerpt 1 talks about the path of the upper thread loop around the bobbin. The "context" here is level 4. The error is on line 1, which was caught and corrected by the speaker on line 2. According to Table 14, the level of the uttered phrase "behind" is level 4, that of its intended meaning "in front" (in this case, its correction) is also level 4. Thus, this is the case where for both the uttered phrase and intended meaning, the context level matches the level of the error.

In contrast, excerpt 2 on the same table shows the case where the context level does not match that of the error. This is taken from an explanation at level 3, which is the level for the context. The error here is the speaker said "bobbin" when she meant to say "needle." "The bobbin" as a thread source is a level 2 term, so is the intended "needle." This error was not corrected.

In the same fashion, for each error's uttered phrase and intending meaning, the match between its level and the context level was

Table 14

Associated phrases for the six levels of understanding.

Level	Phrases
0	stitch, sewing machine
1	thread (in general, or with some distinction like one and the other, but not necessarily upper and bottom), fabric intertwine
2	upper thread, bottom thread, needle, loop (as the thing for the bottom thread to go through), bobbin (as the source of the bottom thread), top spool (as the source of the upper thread) pick up, cross over
3	loop (as the thing to go around the bobbin), hook (as the thing to catch/pull/release the loop), bobbin (as the thing for the loop to go around) go around, catch, pull, release
4	front of bobbin, back side/space of bobbin, side 1 of loop, side 2 of loop, hook (as the thing to separate the loop) (side 1) clear (the front), (side 2) go through (the back), (bobbin) provide (the back space), support, attach
5	bobbin (as the free-floater), bobbin case (to clamp the bobbin onto the machine), bobbin holder, axle (on the holder), collar, hookshaft, machine (to which the hookshaft is fixed) float, (collar) hold/grab/grip (holder), (bobbin case) clamp,

Table 15

Examples of corrected and non-corrected errors.

Excerpt 1:

1 The point I understand is the part going behind
2 be- going in front.

Said phrase: behind : Level 4
Intended meaning: front : Level 4

Context: Level 4

Excerpt 2:

3 And that (= the hook) grabs onto the loop of the thread
4 from the bobbin

Said phrase: bobbin (as a thread source) : Level 2
Intended meaning: needle :Level 2

Context: Level 3

determined. I distinguish three types of match. "Match" means that when the level of its uttered phrase or its intended meaning is n, the level of its context is also n. When the context level is greater than n for a level n error, it is called "under-specified." The argument of the surrounding context is more advanced than the error itself in terms of the hierarchy, thus, the error itself is underspecified. An error on level n in the context of level less than n is called "over-specified," because this is the case the erred term is overly specified for its context argument. In Table 15, excerpt one is a "match." Excerpt 2 is "under-specified."

4.3. Results

Forty-eight errors were detected in all. Other types of verbal correction occurred in the protocols which were not counted as errors. Twice, a general verb was changed to a more specific verb ("take" became "grab" in one; "get" was changed to "unhook" in the other). These were not regarded as errors because the general verbs in these cases were judged by the speakers to be usable in place of the corresponding more specific verbs. Thus, these "corrections" were not errors, just more specification. Seven times, pronouns were changed to nouns: e.g., "this can, the needle thread can..." They were not counted as errors, for the same reason. Once, "comes" was changed to "goes." This was regarded as reflecting a point of views change, not an error.

Thirteen times, exchanges occurred among auxiliary verbs ("it's going to be" became "it has to be"; "don't" became "can't" etc.). Determiners and demonstratives were exchanged also for the total of five times (e.g., "the" was corrected to "a"). These were not counted in the data, mainly because "levels" of these functional words could not be determined.

Table 16 A shows the numbers of corrected and not-corrected errors under each category of "match," "under-specified," and "over-specified" for the uttered phrases. Also, there were three cases where the uttered phrase's level did not belong to any levels. They are counted in the category "off." Table 16 B has the corresponding numbers for the intended meanings. From these tables, the trend is clear: if the error matches its context, it is caught and corrected. This trend appears to be about equal for both the uttered phrase and the intended meaning. Chi-square was computed by collapsing "underspecified," "over specified," and "off" categories into one, to increase the expected frequencies in cells. The differences are significant; for uttered phrases, $\underline{X}^2(1) = 8.75$, $\underline{p} < .01$; for intended meanings, $\underline{X}^2(1) = 5.49$, $\underline{p} < .01$.

Another noticeable trend is that errors were not corrected if they were underspecified. This is more apparent for uttered phrases.

Table 16

Number of corrected and not corrected uttered phrases and intended meanings.

A: Number of uttered phrases.

Category	Under specified	Match	Over specified	Off
Corrected	3 a	15 a	1	3
Not corrected	20	6	0	0

N.B. a: Includes a case where the error was corrected by the listener.

B: Number of intended meanings.

Category	Under specified	Match	Over specified	Off
Corrected	3 a	16 a	0	3
Not corrected	11	9	4	2

N.B. a: Includes a case where the error was corrected by the listener.

If "underspecified" is compared against the combination of "match", "overspecified" and "off," the differences are significant; for intended meanings, $\underline{X}^2$ (1) = 3.46, $\underline{p}$ <.05; for uttered phrases, $\underline{X}^2$ (1) = 16.67, $\underline{p}$ <.01.

4.4. Discussion

One striking result of this report might be the small number of observed errors. The protocols in all have 30,761 words in them. There were 48 errors, for an error rate of 0.0015. People do make errors, but they are not abundant.

The listener corrected errors only twice. Errors were most often detected by the speakers. Errors were caught and corrected if they belonged to the currently focused level. They were less corrected when their appearance belonged to the already known levels. The mechanism for this seems to involve some interactive process of what is known and how the said phrase can be interpreted. Before I go on to this speculation, let me discount simpler explanations.

It is often said that errors in naturally occurring dialogues are let go because they are not attended/processed enough. In my data, because it was the speaker who most often corrected errors, you cannot say they were not processed. Erickson and Matson (1981) also showed that subjects who read aloud the erroneous questions still answered them, as if they did not notice the errors. We need a better explanation.

The speed of the speech might be a factor. When people do not catch errors they might be talking fast. Because the protocol was divided into groups by "breaths" I have an estimate of a measure of speed of speech: the number of words said per breath. Five lines before the uttered phrase are taken for each error and the average number of words per breath was computed. This computation was possible for 24 cases, 10 for corrected, and 14 for non-corrected errors.[7] Table 17 has these numbers. When the total number of words spoken is divided by the total number of lines from all the protocols, the average number of words per line is 4.2. The difference between the speed of corrected, matched errors and that of non-corrected, matched errors is significant,

7. Other 24 cases, this computation was not possible because of the following reasons: correction and non-correction occurred consecutively so the status of the preceeding lines was ambiguous (10 cases); errors occurred right after the turn opened (10 cases); correction was made by the listener (2 cases); correction was made while the speaker was drawing and talking sporadically (1 case); and where the preceeding sentence included some inaudible portion (1 case).

Table 17

Average number of words said in one breath before the error. Standard deviations are shown in the parentheses.

Category	Under specified	Match	Overspecified and Off
Corrected	-	4.11 (1.12) n= 6	4.03 (1.64) n= 4
Not corrected	4.01 (2.00) n= 9	6.32 (1.21) n= 5	-

N.B. n = Number of cases.

$\underline{t}$ (9) = 3.78, $\underline{p}$ <.01. The difference between the speed of non-corrected, matched errors and that of non-corrected, underspecified errors is also significant, $\underline{t}$ (11) = 2.69, $\underline{p}$ <.05. These imply even when the uttered phrase belonged to the level of current understanding, if the subjects were talking fast, the errors were not caught. This seems to give a plausible explanation why some of the matched errors were not caught. This still does not explain why underspecified errors were let go. They were not embedded in particularly fast speech.

Examination of underspecified errors reveal that often the uttered phrase is a more general term than its intended meaning. "The bobbin" was called "the machine"; "The thread" was called "the material." Though original speakers did not think they would usually call them by those names, a bobbin is a machinery; a piece of thread is a material. The uttered phrases were therefore technically correct. Out of 20 non-corrected, underspecified uttered phrases, 9 cases fall into this category. There is no such case in corrected errors. This suggests a tendency that when a known fact is expressed in general terms, they allowed interpretation in a reasonable range because of their generality, and the errors were let go even they do not hit upon on the right meanings.

People seem to catch and correct errors in their own speech when the errors belong to their level of understanding, unless they are talking fast. When the uttered phrase belongs to an already known level, people seem to interpret it somehow, and the error does not get corrected as often. The possibility of interpretation hidden in the known level phrases appears to be at least partly responsible for this error detection pattern.

5: OBSERVATIONS TOWARD CONSTRUCTIVE INTERACTION

5.1. Introduction

In this last chapter, I list some of my observations and link them to work on the "statistics" interaction. I try to specify further the observations I made in the statistics interaction in terms of the framework I reached through the sewing machine analysis. I also add two new observations. This last chapter should really be treated more like a proposal for future work than a final report.

In my analysis of the statistics interaction in Chapter 2, I listed five observations, two characteristics of purposeful conversations and three "conditions" for such a conversation to work constructively. There, "constructively" meant that participants changed their old schemas, thus gaining new pieces of knowledge. In the first section, I re-interpret this schema change as a focus change, and show a new way to read the old protocol. The issue of "focus" was also one of the main topics in my sewing machine analysis, though types of focus talked about are different. By sorting out these differences, I try to suggest a way to investigate the issue of "focus" in research on understanding.

In the work on the statistics problem, it was observed that the two participants had different "starting schemas," a situation that helped them come to a constructive conclusion. This point is related to the observations of criticisms in the sewing machine analysis. Starting positions and end results are individualistic; the value of interaction comes from the different understanding of the current topic that the participants apply to the interaction. This allows the participants to provide each other useful validation checking mechanisms that are not easily available individually.

There are two more interesting observations made in the sewing machine protocols. The first observation concerns the division of labor seemingly responsible for promoting interactions: the person who is not currently engaged in the "local" task at hand shows a greater tendency to bring up a new "motion," some of which lead to a new and better phase of interaction. This will be talked about in the fourth section. The second observation is directly related to the function-mechanism hierarchy I proposed in the first chapter. The understanding proceeds more smoothly when the interaction moves from upper levels to lower levels. The implication of this is discussed in the last section.

5.2. The issue of 'focus'

5.2.1. Focus change as schema change -- Statistics protocols revisited

In my work on the statistics problem, my goal was to identify conditions for schema changes. The situation was an interaction between a professional psychology researcher (R), who had completed an experiment, and a non-professional, but skilled statistician (S), who was hired to do the data analysis for R. The purpose of the interaction was for R to explain to S what to do. R, however, did not have all the analyses worked out, and came up with a new way to analyze her data through this interaction.

R was interested in the different roles that nouns and verbs play in sentence comprehension. Her hypothesis was that verbs are more "relational" and thus change their meaning according to the accompanying nouns. Nouns are not as flexible. R tested this hypothesis by using a paraphrase-restore design: one set of subjects paraphrased some original noun-verb combinations (in the form of sentences) and the other set of subjects tried to restore the original nouns (or verbs) given only the paraphrases. R hoped to argue that the verbs were not as easily restored as nouns, implying that the verbs tend to change meaning more than do the nouns.

The most apparent way to test this hypothesis is to see th difference between the group who restored nouns and those who restored verbs. This much R knew before the interaction. She further hypothesized, however, that the verbs would change their meanings more in less meaningful sentences (e.g., the verb "agree" should change its meaning more in "the courage agreed" than in "the daughter agreed"). She did not know how to analyze this. It was S who pointed out that this latter hypothesis could be tested by comparing performances on "good" combinations and "bad" combinations. Thus, through the interaction, R came up with an Analysis of Variance (ANOVA) of noun-verb by good-bad combinations to treat both of her hypotheses. This phase was said to be "constructive," and the process to reach there was analyzed.

My analysis of this interaction yielded the following list of "conditions" for this "schema change."

Conditions for schema change:

1. The schema to change has to be looked at globally:
   The part of the protocol immediately preceeding the change suggested that R was looking at her experimental design globally,

compared to focusing her attention to the noun-verb group comparison.

2. The schema has to be examined at the precise place where the change should occur:
R´s attention had to be drawn onto the "word combinations" four times before the change took place.

3. The existence of different "perspectives" was useful:
S, who was less knowledgeable of the experiment, could still guide R´s change. The reason for this seems to be that S was mainly interested in finding factors for ANOVA, and this different "perspective" helped.

The "discovery" of the new factor (good-bad combinations) was regarded as a case of "schema change" in my earlier analysis. What is changed there, however, is not the content of R´s knowledge (i.e., it was not the case that R came to know more about her experimental design), but rather, how to look at it. It was a case of "focus" change. The conditions listed above really apply to changes of focus, not changes of schemas.

5.2.2. The notion of ´focus´ in the sewing machine analysis

"Focus" has been a hidden, but important issue in the sewing machine analysis, too. C-POV is one way to talk about it. There, the focus was literally on some part of the physical sewing machine. As shown in Chapter 3, C-POV was shown to be related to the process of understanding.

The function-mechanism hierarchy is the other. The implicit notion underlying the error detection analysis in Chapter 4 was that when a subject was on level n, that level was "in focus," while the others were "out of focus." Steps assumed for progress of understanding (Chapter 3) can also be translated into focus change. A function on level n is "focused" as problematic. Then, its mechanisms gradually come into focus, as its search proceeds. When a mechanism is established, the whole mechanism is in focus. After that, one of its subfunctions has to be focused upon. In terms of the function mechanism hierarchy, the first condition (that the schema has to be globally looked at) would mean that a mechanism on level n has to be well known in order for its subfunction to be a guiding question for the next level search.

The second condition (that the precise point of change has to be looked at) was based on an observation that the key phrase for R´s change, "word combinations," appeared in the protocol three times before the change, without causing the change. In terms of "focus," this condition seems to mean that for a key phrase to have effect, it has to be processed in the right focus. To see this, consider the four excerpts from the statistics problem interaction for the four occurrences of "wor combinations" again (Table 2 to 5 in Chapter 2). The structure of focuses in this interaction can be depicted as in Figure 18.

On the first occasion, R was explaining to S the first phase of her experiment. It is natural to say that R's focus was on the experiment, rather than on the analysis. On the second occasion, although R was talking about the analysis, R's focus was on the comparison between noun-restore group and verb-restore group (the first order analysis). After this excerpt, R explained how she had created these stimuli for about 60 lines, but at line 428, she concluded by saying, "let's do the rougher things first." Because her focus was on the noun-verb comparison in the first order analysis, the word combinations were seen as a structure of stimuli rather than a possible factor.

On the third occasion, R's focus seems to have been narrowed down to the analysis even more. R is now looking for factors to incorporate into an ANOVA design. The problem is that her focus was still on the first order analysis: Her main concern was to get the result of "verb changes meanings more than nouns." The analysis of "sets," the "hygienic" variable, was needed on that level to show the homogeneity of her stimuli. She finally moved her focus down to the second order analysis in the fourth occasion. This can be deduced from her expression, "I'm not very interested in whether it (ease of restoring) varied across the sets ... I'm much more interested in knowing whether it varied across word (combinations)" (lines 560-569). Here, being in the right focus, she immediately saw the possibility of incorporating the word combinations as a factor in the ANOVA design.

Similar incidents were twice observed in the sewing machine protocols. The "key phrases" used in their conclusions were used by one member sporadically throughout the interaction, without affecting the other. Defining the scope of a focus as being on "a mechanism" (while mechanisms are searched, proposed, and established) or on "a function" (while functions are identified and questioned), we should expect that the same expression communicates best when two members are in the same focus.

One case occurred in pair A. A1 started to use the phrase "collar" to describe the way the hookshaft holds the bobbin holder. A1 used this phrase three times at different points in the interaction. For the first two such occasions, A2 did not respond much (apparently the phrase did not mean too much to him). In the following three figures (Figures 19, 20, and 21), the understanding path to the point of ach occasion is shown with the short excerpt of how it was said. In the first occasion, A1 said "this thing just forms a collar," leading himself down to level 5 while A2 was still on level 4. In the second occasion, though both of them were at level 5, A1 was on the standard solution while A2 was on an alternative. But on the third occasion, after both of them reached a standard level 5 solution, they had no

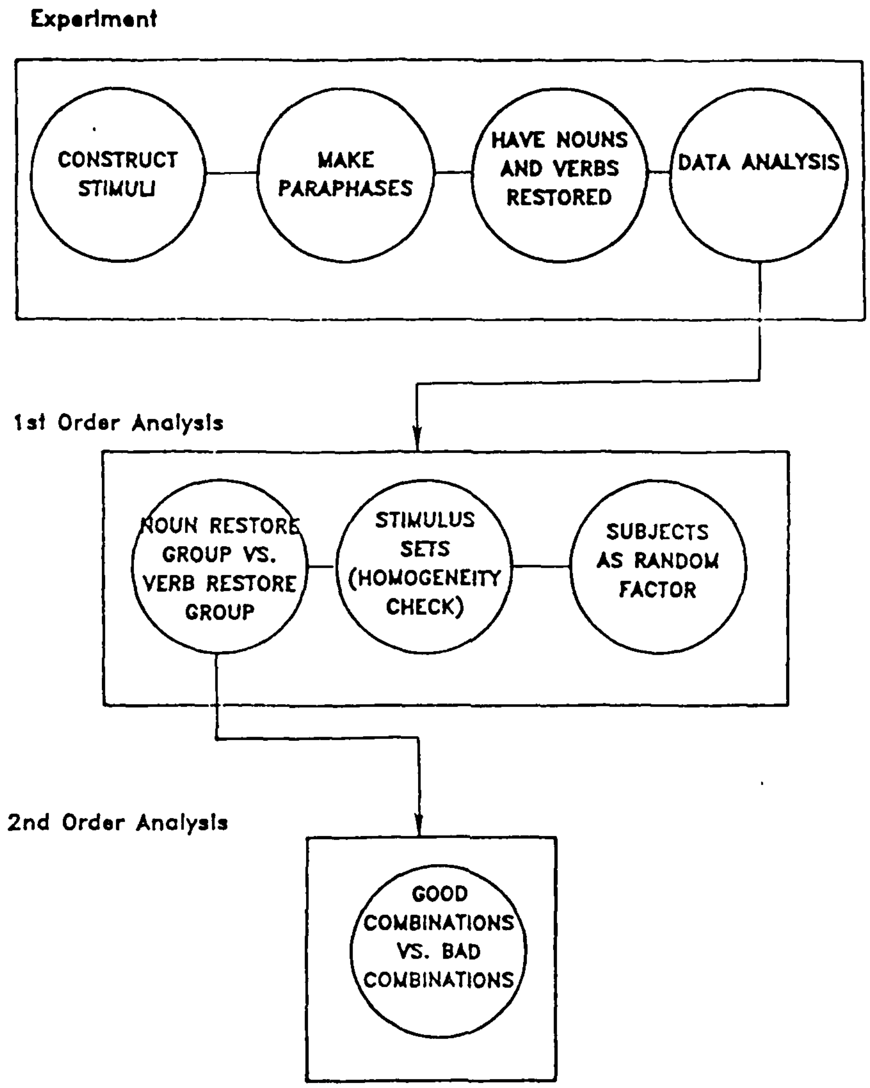

Figure 18. The structure of focuses in the statistics interaction.

Collar: first occasion

1255: A1: well one thing
1256: one thing that's interesting as I move this back and forth
1257: look at the case at the bobbin's resting
1258: fist of all
1259: it's not
1260: rigid
1261: A2: uh huh
1262: A1: it doesn't have a rigid attachment
1263: A2: well
1264: A1: so
1265: A2: I mean that it wiggles
1266: A1: yeah
1267: okay I'm only saying it's not bolted
1268: it's not real rigid now suppose
1269: that th[illegible]
1270: this thing
1271: just forms a collar
1272: I don't know if this will all work
1273: A2: well
1274: A1: this forms a collar
1275: that holds this
1276: but there is actually some space behind it
1277: (pause)
1278: A2: uhhh

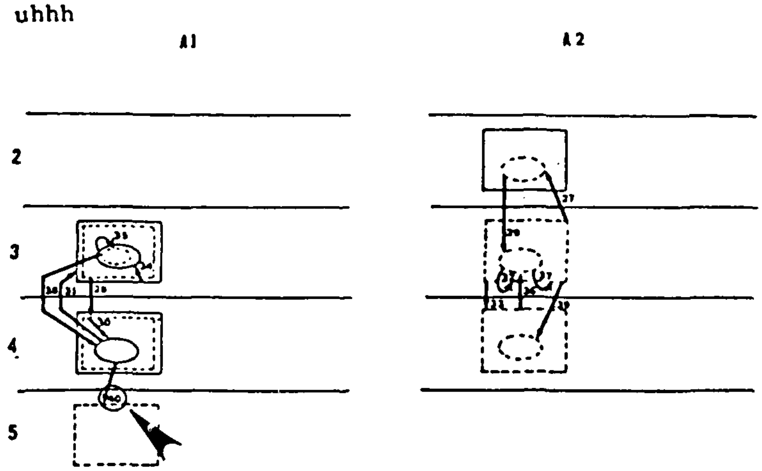

Figure 19. The first occasion of "collar." The move after which the word "collar" appeared is pointed to by the arrow.

Collar: second occasion

1333: A1: that this thing is really loose in here
1334: and
1335: and the
1336: thread slips behind it
1337: and that's just held in by sort of a collar
1338: this
1339: this thing that's moving around sort of forms a collar
1340: A2: well
1341: A1: now I'm not sure if still we can work out the geometry
1342: A2: what I mean is
1343: (pause)

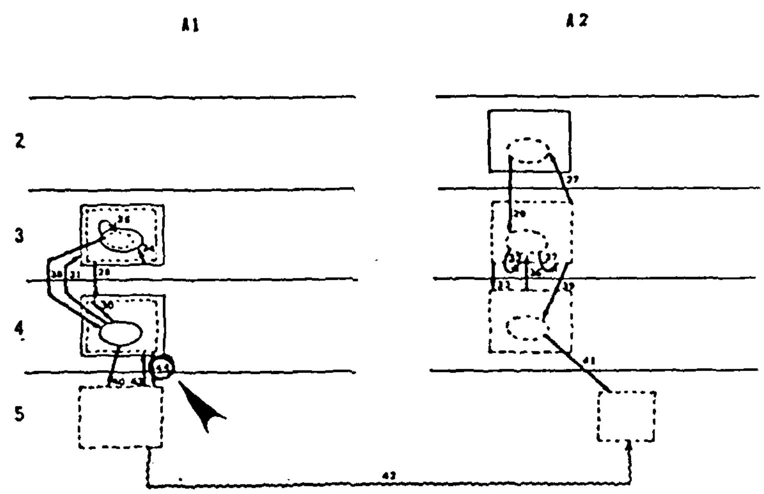

Figure 20. The second occasion of "collar." The move after which the word "collar" appeared is pointed to by the arrow.

Collar: third occasion

2252: A1: see I think that's grabbing it i think that
2253: A2: ooohhh
2254: A1: that again I
2255: think this whole thing is just loose in here
2256: held by the collar
2257: A2: yeah it
2258: it's
2259: it's held by the collar
2260: A1: right?
2261: and this grabs it and just shoves the thread around [illegible]
2262: A2: yeah
2263: okay

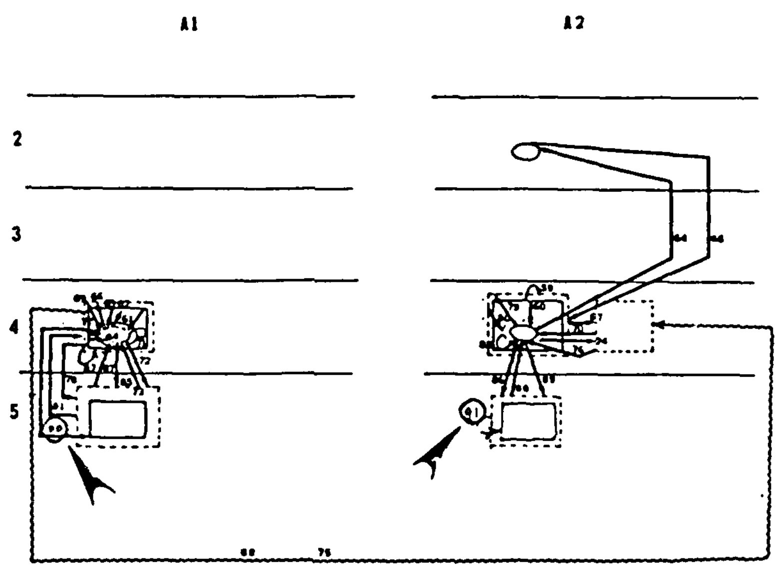

Figure 21. The third occasion of "collar." The moves after which the word "collar" appeared is pointed to by the arrow.

trouble communicating with the phrase "collar."[8]

A similar thing was observed in pair B interaction. The key phrase there was "floats," to describe the way the bobbin was attached to the machine. B1 used this phrase, from her experiential knowledge, which did not mean much for B2 until he came to understand what was actually happening at level 5. Figures 22, 23, and 24 show the corresponding excerpts and paths for the three occasions where the phrase "float" appeared in their protocol. In the first occasion, not only they were on different levels but also B1 skipped level 4 and gave a level 5 explanation abruptly. This abruptness could have contributed to B2's difficulty in interpreting B1. For B1, the expression "the bobbin floats" came from experience, but did not have a substantial meaning in terms of physical connections of the bobbin mechanism. In the second occasion, B1 tried the same phrase while B2 was questioning the level 4 standard function. B2 could have been ready to accept a level 5 explanation, but apparently B1's answer ("I think it floats") was not "explanatory" enough. B2 did accept this expression when he was on level 3 in the third occasion, suggesting that once being established on level 5, "float" was a reasonable expression for him as well.

Thus, both the "collar" and the "float" cases were similar to the "word combination" case. For the key phrase to be effective, the place to change must be in proper "focus."

5.2.3. Further research on focus

"Focus" appears to be an important topic for understanding both the process of understanding and the structure of interaction. I tried a tentative analysis of re-nominalization on my protocols. That is, I looked to see where people re-introduce the noun, (e.g., "bobbin,") after use of the pronoun (e.g., "it"). The tentative result shows that the structure of re-nominalization matches the structure of steps and levels identified by my coding scheme. I have not collected enough data to report the whole picture here, but the analysis looks promising. Once this type of correspondence is established, it should be possible to use "discourse rules" as a tool to identify "focuses" in interactions, simplifying the coding.

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8. I am not claiming that "collar" meant exactly the same thing to them. In fact, in one of their post-interaction interviews, they defined the word "collar" slightly differently (for A1, collar could mean the whole outer casing; for A2, it meant the ring-shaped lip of the case which prevents a thing inside from falling out). This difference, apparently, did not prevent them from communicating when they were talking about the "same" mechanism.

Float: first occasion
(Ex stands for Experimenter.)

2185: B2: aand
2186: part of it goes
2187: in
2188: front
2189: and part of it goes behind
2190: B1: uh huh
2191: yeah that's where we get the twist
2192: (pause)
2193: B2: aand it goes around
2194: B1: I think it's hard to do the way you're
2195: (pause)
2196: why don't you let me be the hook
2197: 'cause you're
2198: [illegible]
2199: B1: you're floating free
2200: okay
2201: Ex: what is floating free?
2202: B1: the bobbin
2203: B2: okay

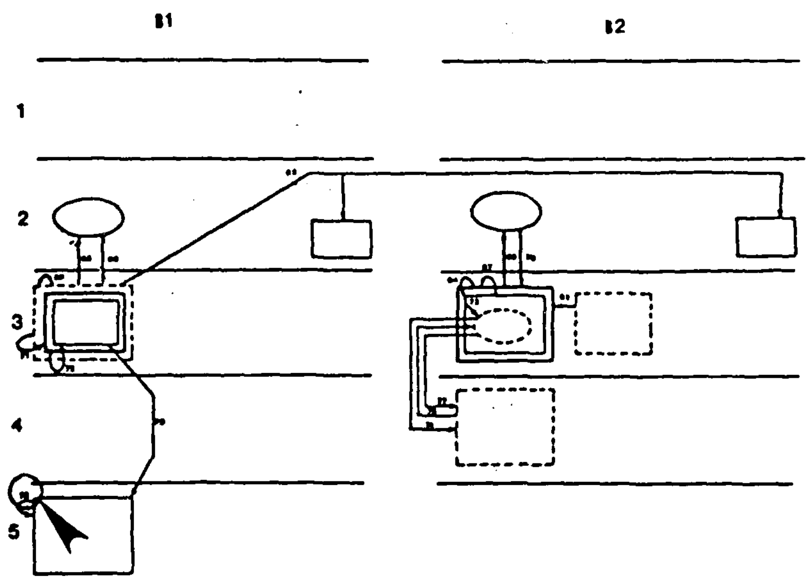

Figure 22. The first occasion of "float." The move after which the word "float" appeared is pointed to by the arrow.

Float: second occasion

2388: B2: how
2389: does that loop in back past whatever shaft
2390: this bobbin must be on
2391: maybe there is not any shaft
2392: B1: let's take it apart and see
2393: B2: where is it uh
2394: connected
2395: (pause)
2396: where is this little piece of machinery connected to
2397: B1: I think it floats
2398: uh
2399: B2: that would be the answer then
2400: floats
2401: B1: oh
2402: (pause)

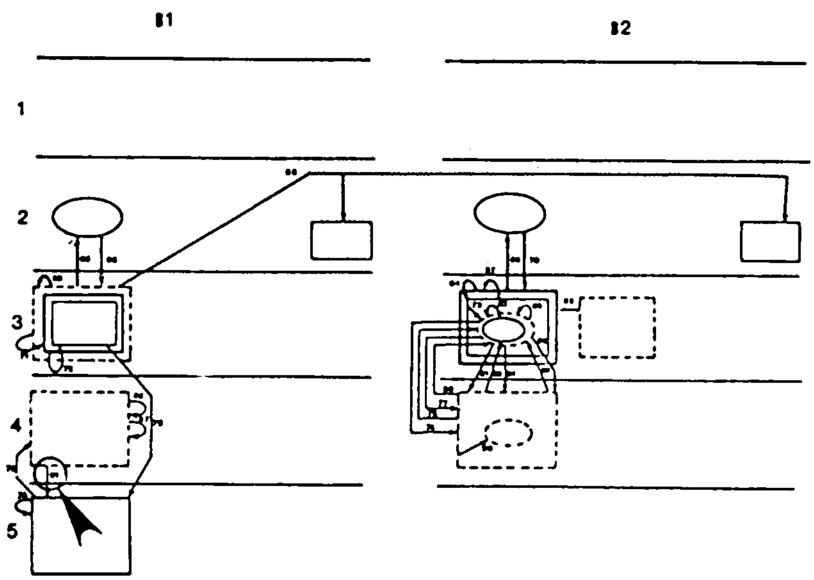

Figure 23. The second occasion of "float." The move after which the word "float" appeared is pointed to by the arrow.

Float: third occasion

2893: B2: it's floating and it's held in a ring
2894: and the uh
2895: the thread passes in front and in back
2896: B1: yeah you know what's oh so it's just
2897: held by
2898: B2: ring like
2899: B1: oh I see if this is got a groo-
2900: this thing got a groove in it
2901: B2: right
2902: B1: the plastic floats in the groove
2903: B2: right
2904: B1: so that's the free float
2905: okay that's the free float
2906: B2: free float
2907: right

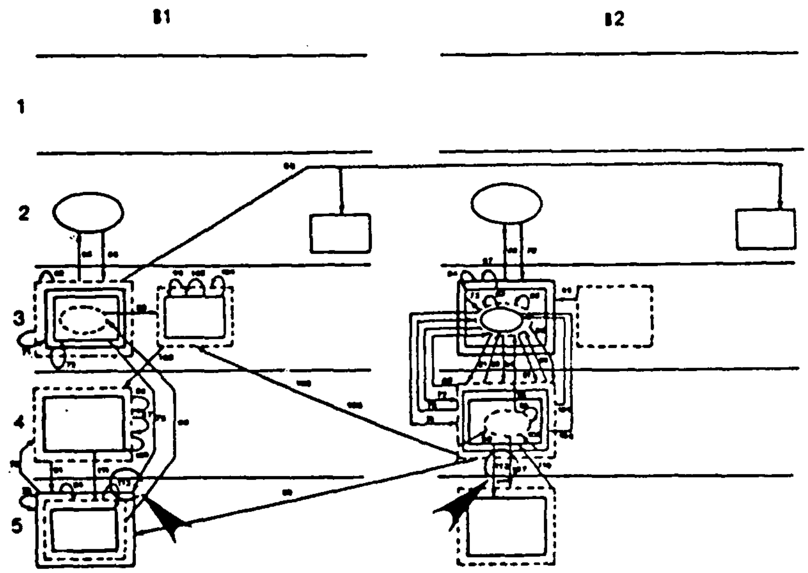

Figure 24. The third occasion of "float." The moves after which the word "float" appeared is pointed to by the arrow.

5.3. Criticisms--validation checking from others

In two person interactions, two participants most usually have different sets of experience on the same topic. One of its consequences is that participants spend most of their time and effort on their own problems. Still, two person interactions have their own virtues. "Criticisms" give opportunity for observing how two sets of knowledge interact.

5.3.1. Starting and ending of interaction are individualistic

Two observations made on the statistics interaction protocols are:

1. The starting schemas are individualistic and have high inertia: It was observed that each member started the interaction with her own understanding of the situation, and this schema guided the course of interaction throughout.

2. Terminal schemas are not the same for the two participants: Each member came to a different conclusion at the end.

Both observation apply to all three sewing machine protocols.

Starting schemas. For four subjects, A1, A2, B2, and C1, there was enough indication in the protocols about their starting schemas. For C2, this was obtained in the pre-session. It is apparent that these starting schemas had high inertia for each one of them.

A1 believed that "the loop goes around the out side of the cage (which holds the bobbin in)" from the very beginning. This, in essence, was right, so it is not surprising that he did not change his starting schema very much. A2's central notion about the bobbin was that it was firmly attached to something, and that attachment should prevent the loop from going all the way around the bobbin. He did not discard this notion until very late in the protocol where he saw the analogy between a spokeless bicycle wheel and the bobbin mechanism.

B2 created his starting schema immediately after the interaction opened. His "loop in loop" solution was also very robust against B1's objections. B1 kept complaining, based on her own experiences. In this sense, these complaints must have come from part of her starting schema. But because it is embedded in her experiential knowledge, it was never obvious what exactly her starting schema was.

C1 seems to have created her starting schema from viewing other pairs' tapes: The upper thread loop had to go all the way around the bobbin. Because this phrase contained the actual solution, she did not have to change it. In her case, the high inertia is seen in that she committed herself to this phrase for more than forty-five minutes without seeing any solutions in it. C2 did not say enough to allow analysis of this point.

Though it appeared general, this high inertia might reflect a demand characteristics of the situation. I was present at all the interaction situations as an observer, "demanding" that some interaction keep going. R felt obliged to inform S as much of her experiment as possible. A1 and C1 knew they were to tell the other how the machine worked. If an expert had explained the whole mechanism to them, the interactions might have been much shorter. The observed high inertia seems to be a characteristics of cooperative, interaction between peers, where there is some demand (or motivation) for it.

One question reasonably raised in the statistics interaction analysis was how much "breaking force" is necessary to change schemas. For pair A, the change came because of A2's objections, while A2 did not change his basic belief until he saw the analogy. For pair B, the session had to be changed. Pair C, who carried on their starting schemas almost to the end, needed the experimenter's help.

Terminal schemas. In the sewing machine interactions, all subjects "established" a level 5 mechanism at the end. Comparing their level 5 mechanisms should give us some idea how closely two members of each pair came to share their solutions. (Figure 25). Their level 5 mechanisms were not very similar, suggesting support for the observation made in the statistics interaction that end result of interaction could be individualistic.[9]

For all pairs, one gave a more extensive mechanism while the other gave a much simpler one. This may be an artifact: if one participant gives an exte[illegible]e answer, there is no need for the other to repeat it, except for [illegible]e most important or different parts. In this sense, differences seen in Figure 25 are those the subjects cared enough to express. More subtle differences could have been there.

One such hidden difference was revealed in the drawings used by A1 and A2 at the very end of their interaction (Figure 26) while they were summarizing their conclusions at the experimenter's request to "explain how the sewing machine works as if to a person who doesn't know anything." Notice that their points of view are different. A1 drew a cross-sectional view, as he had been doing throughout the interaction. A2 drew a front view, even though the drawing he most often dealt with in the interaction was A1's cross-sectional view. I suspect that this reflects his spokeless bicycle wheel analogy more honestly---it looks more like a bicycle tire than A1's drawing does.

This difference again showed up six months later, when they were asked to give a "TV lecture" to an unknown audience, using a blackboard, in front of a video camera. They were asked to explain how the machine

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9. Hobbs and Evans (1980) suggest, based on their analysis of plan-based mechanisms for conversation, it is the norm of conversation that people do not talk to each other.

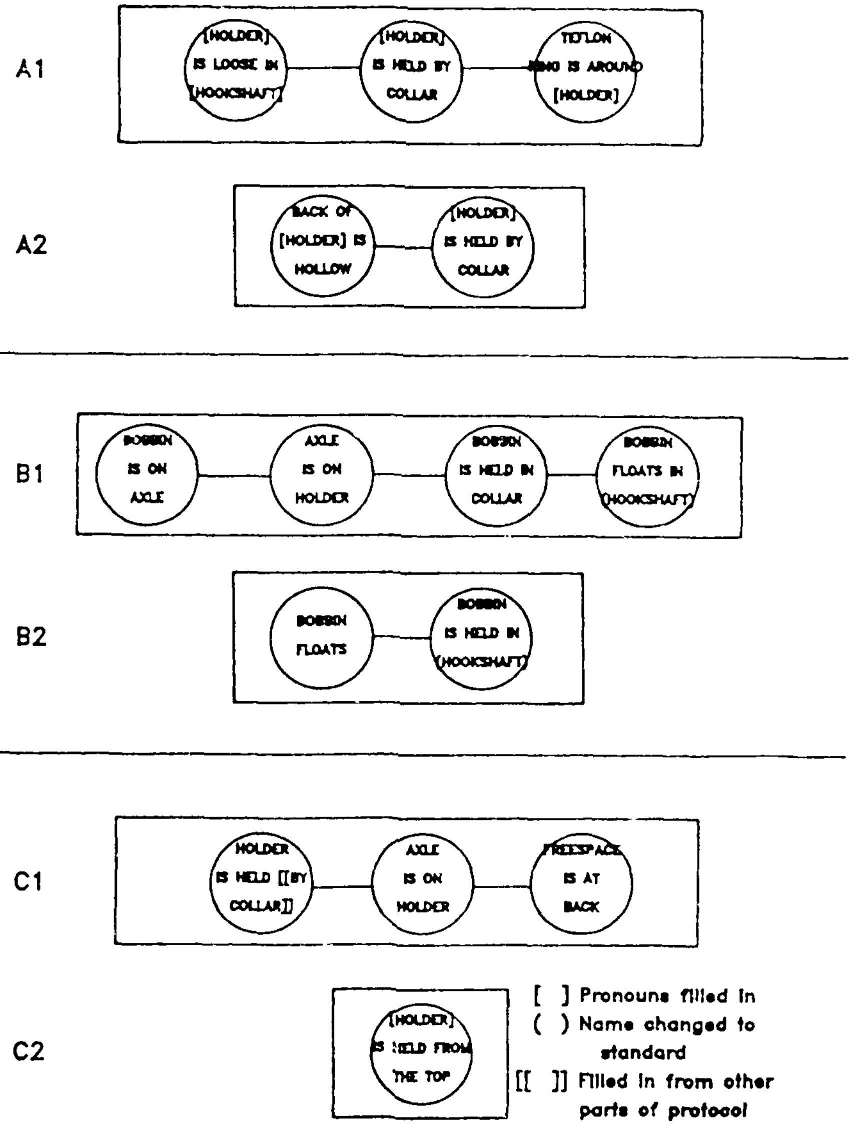

Figure 25. Level 5 mechanisms reached by the subjects. When pronouns were used in the expressions, they are nominalized and put in brackets ([ ]). When non-standard names were used, they are changed to standard names given in the Appendix 5 and put in parentheses. When a part was not explicitly mentioned in the level 5 mechanism but was still safely inferred by the author, it is put in double brackets ([[ ]]).

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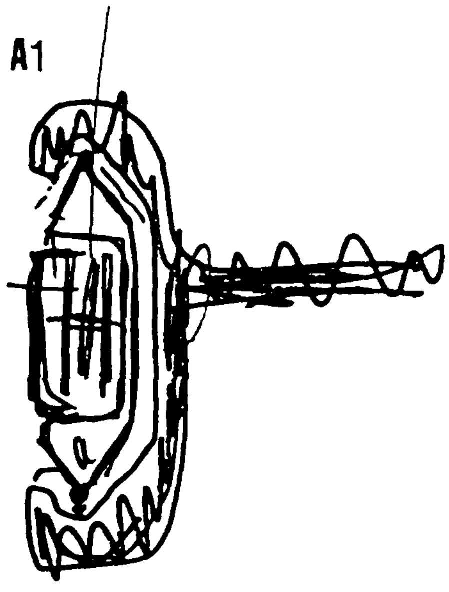

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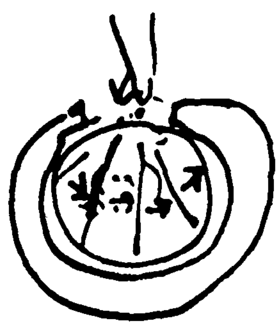

Figure 26. Drawings used by A1 and A2 to illustrate the bobbin mechanism.

made its stitches. A1 gave essentially the same explanation he summarized at the end of the interaction. He re-drew his cross-sectional view of the bobbin structure as in Figure 26. A2 used a front view of the bobbin, made a notch in the bobbin to catch the upper thread loop and rotate the bobbin rather than the collar to make the loop go around the bobbin (he said that he used this "wrong" explanation to simplify). The way he understood the mechanism in terms of the bicycle wheel analogy (i.e., the bobbin is analogous to the tire) was directly used in his explanation here.

5.3.2. Criticisms provide validation checking mechanisms

If the starting and ending of interactions are individualistic, what could be the virtue of "working together"? Individualistic starting schemas mean people interpret the problem/situation in their own ways. The high inertia of their starting schemas mean they tend to work on their own problems. The individualistic ending implies they find their own satisfactory solutions.

What is not here is a mechanism to validate their individualistic solutions. Because they work on their own problems in their own way, it is reasonable to assume they do not have easily accessible checking mechanisms for the validity of their solutions. This is where the virtues of two people occur. Because each participant works on different starting schema, what is most obvious and natural to one may not be so to the other. This leads to "criticisms." In this sense, criticisms are the expression of validation checkings, and studying them should reveal some fact about these validation checking mechanisms.

5.3.3. Different perspectives as the source of criticisms

Table 18 lists the numbers of criticisms observed in the sewing machine protocols, according to where they occurred in terms of "levels." Self criticizing accounted for only 12% of the incidents (5 times out of the total of 41), implying that validation checkings are indeed hard to obtain within an individual system. When the criticism was directed at the other person, pair A most often preferred "downward" directions. Pair B (in fact B1) preferred to criticize "from experience", (which were in a sense also "downward," because most of her experience belonged to higher level knowledge such as what a completed stitch should look like).

"Upward" criticism refers to the situations where a person who understands more (and is therefore at a lower level) criticizes the other, who understands less (and is therefore at a higher level). This sounds like it should be the most common form of criticisms, but the observed frequency for this category is not high (3 times). "Downward" criticisms mean the person who is criticizing has less understanding (and is on a higher level). This is probably more like a "complaint" than an evaluative criticism. It perhaps means that the criticizer cannot understand the proposed mechanism. Criticizing the level on which both are working (Mn -> Mn) is also rare (4 times). It seems,

Table 18

Number of criticisms observed in the sewing machine interactions.

	Pair			
	A	B	C	Total
Criticisms directed to self				
Same level				
Same M (Mn -> Mn)	1	-	2	3
Different level				
Upward (Mn -> Mn-i)	-	1	1	2
Criticisms directed to other person				
Same level				
Same M (Mn -> Mn)	-	4	-	4
Different M (Mn -> M′n)	4	2	1	7
Different level				
Upward (Mn -> Mn-i)	-	3	-	3
Downward (Mn -> Mn+i)	12	2	-	14
From experience	-	8	-	8
Total	17	20	4	41

therefore, that criticism occurs when the two people are at different levels, having different focus. It is not simply that one person knows better than the other, or that both participants work on "the same problem."

There seems to be an individual difference in the tendency to give criticisms: A2 gave 15 criticisms out of the 17 for pair A; B1 gave 16 times out of 20 for pair B. This might be a result from the two people assigning different roles to themselves. There also seems to be some individual pair difference: pair C gave many fewer criticisms.

5.4. Motions--The role of the observer

Another easily observable characteristics in the protocols is that of "motion," when one person suggests a new way to approach the problem. Near the end of the pair A interaction, A2 suggested taking off the bottom panel of the machine, so that they could get a better view of the backside of the bobbin, which led them to their final conclusions. During their "loop in loop" stitch struggle, B1 suggested starting from a completed stitch, which brought them back onto the standard path.

5.4.1. Who starts the motions?

Motions can either be "innovative" or closely related to their topic in question at the time. The above two examples are both rather innovative. A second kind of motion is "topic-related," for example, to suggest going back for more observation. Table 19 shows the numbers of these two types of motions. If we compare members in each pair, topic-related motions were generated more by A1 and C1: A1 and C1 were both "instructors." (In pair B, B2 was more of the leader, but B1 was more knowledgeable in actual sewing.) A2, B1, and C2 gave more "innovative" motions. They were the followers. From what we generally know about instructor-student relationship, it seems safe to say that instructors were more directly engaged in initiating solutions while their followers were observing. In this sense, it is not surprising to see more topic-related motions made by the instructors. An interesting point is, the above data, though few in number, suggest that innovative motions were most frequently initiated by "observers."

This is related to the issues of "focus." It could be assumed instructors were more engaged in the local "focus." "Observers" could have had a more global focus, not being able to narrow down their focus to match their instructors. Innovative motions might have their origins in this global focus which was not easily available to the "instructors."

One reason why there was no clear case of motion in the statistics interaction might be the differences in the roles of the two participants. R was a professional psychologist, S was hired by her to do just the analysis. The topic was R's experiment. The "word combination" analysis could have been brought up as a new motion. It was S, the follower, who first brought this up. The pattern is the same, but the actual way S raised it was very subtle and indirect (see excerpts in Tables 2 to 5 in Chapter 2).

Table 19

Number of motions observed in the sewing machine interactions.

	A1	A2	B1	B2	C1	C2
Topic-related motions	6	0	4	3	7	2
Innovative motions	1	4	6	2	1	3

5.4.2. Motions are constructive

Although topic-related motions usually did not change the course of interactions very much, some innovative motions worked constructively. Out of the total of 17 innovative motions, 6 were followed by some change in the course of the interactions.

Once, A2 started to used fingers to simulate the threads, which made A1's discussion back up one level. A2's motion to take the bottom panel off the machine led both of them to level 5 mechanisms. One of B1's suggestion to use thick yarns to simulate the threads did not have an immediate effect, but led B2 to explore possibilities of his "loop in loop" solution later on. When B2 was deeply engaged in this exploration, B1 suggested starting from a completed stitch, thus going backwards, which brought both of them back to more standard path. Near the end of session I, B1 also suggested going on to machine observation, which they did (the experimenter complied to her motion). B2 suggested takeing the whole top cover off the machine near the end of their session. (This was changed to take the bottom panel off by the experimenter because it was much easier.) This led them to their level 5 conclusions. Within these observations, innovative motions seem to have a potential to lead the interaction in a constructive fashion.

5.4.3. The division of labor in knowledge acquisition

The data on motions seem to suggest the role of the followers or the observers in two person interactions. They start innovative motions which are potentially useful. Similar observations were made in the "criticisms" section. The one who apparently understands less contributes by criticizing the other. Combining these two observations, a speculation about the "division of labor" in two person, constructive interactions is possible. While one person, who has (or who thinks to have) more to say about the current topic takes the "task-doer's" role, the other becomes an observer, monitoring the situation. The observer can contribute by "criticizing" and "making motions," which are not the primary roles of the task-doer.

5.5. 'Downward' search--it's easier if you know where to go

In this section, I talk about a somewhat vague but general tendency of successful vs. unsuccessful patterns of interaction. Having no proper definition of success or failure of interactions, I use here the "sense" of participants as a clue. Sometimes they felt they were stuck, other times they kept going even though I as an observer did not think they were going anywhere. Although there must be many reasons to feel "stuck,", one of which appears to be related to the way their search was going in terms of the function-mechanism hierarchy: They felt stuck when they were searching upward. Because no strict measure has been developed for this analysis yet, I simply elaborate on my observations, relate that to the issue of focus, and speculate why the upward search could be harder than the downward search.

5.5.1. 'Downward' search and 'upward' search

Downward search is the search for a mechanism when a function is known: The question is how that function is done. This search involves finding out constituent functions on one level down and the relationship among them. Upward search is the search for a function when the constituents (another set of functions) of a mechanism are known: Here, the question is what is the higher level function that the known constituent functions are supposed to serve. This search involves finding out the relationship among the known functions as well as their higher level function. If one knows that the upper thread loop goes around the whole bobbin, but does not know how, this leads to a "downward" search. If it is know that two threads are involved in creating a stitch, but the actual interaction is being looked for, this is an "upward" search.

5.5.2. 'Upward' search appeared to be harder

Evidence from the sewing machine interactions. In the sewing machine interactions of pairs A, B, and C, there were four cases where participants apparently felt "stuck." A1 felt "almost paralyzed" (his own words) when he tried to put bits and pieces of "known" machinery together so that they would allow the upper thread loop go around the bobbin. B1 said she was stuck when she got confused with the actual interaction of the stitch by B1's "loop in loop" solution. C1 felt stuck twice when trying to make the upper thread loop go around the bobbin while simulating the thread movement with the yarn.

The common characteristic of all these cases is their searches were of "upward" nature. A1 thought the slot on the bobbin case should do the trick. Both B1 and B2 knew there were only continuous threads (i.e., with no free ends) to create a stitch. C1 knew the upper thread loop had to go around the "bobbin," which meant a bare bobbin in the first occasion and the bobbin in the case in the second. They were searching for how these "known" pieces could be related to some intermediate unknown function, which they then hoped would relate to the known function (i.e., stitches).

This subjective observation that these searches were upward in direction has some support from the protocols. In two of these four cases (pair B and C), the "observer" of the situation suggested completing a stitch and going backwards from there. Their expression of "going backwards" suggests that at least one participant of those pairs felt that the search direction could be changed.

Evidence from another set of data. In a set of short experimental observations on different subjects who also worked on the sewing machine stitch problem, each member of a pair of subjects was given some information about the sewing machine stitches during a pre-session. Pairs of subjects were formed so that the members would have complementary pieces of knowledge about the sewing machine stitch problem. For instance, if one examined the sewed material, the other was given a chance to operate and observe a machine. The pre-sessions included all the necessary information for them to reach at least a level 3 standard solution (i.e., the upper thread loop goes around the entire bobbin to create a stitch), and possibly to go on into the search of level 4 and 5 mechanisms. The point I wanted to observe was how they would discover further problems in a level 3 mechanism (e.g., "how can a loop go all the way around the bobbin if the bobbin is attached to the machine?"). The result was that 9 pairs out of the 11 could not reach the level 3 solution. (One pair found the solution but did not go any further. One participant of another successful pair had known roughly the level 5 answer and convinced the other.)

The common course of events was that at the opening of their interactions they exchanged what they had gained from their pre-sessions. Oftentimes these verbal exchanges included the "correct" expression of the standard level 3 solution. They then believed they had finished the task. Then the experimenter provided them with two pieces of yarn and asked them to simulate what they had just expressed. They suddenly felt unsure and often did not know why they could not simulate what they had just explained.

When they started the yarn simulation, what they usually did was to role play. One person became the needle, the other took the responsibility of the bobbin thread. It was relatively easy for them to make a loop from the upper thread. The bobbin thread was most often just laid down on the desk. One thing they commonly did not do was to confirm the actual stitch on the yarn. They did not confirm what they were supposed to accomplish in terms of the yarn interaction in their simulation. In other words, their search was upward: They manipulated the yarns in the hope that enough manipulation would produce a stitch.

5.5.3. Why is the upward search difficult?

The reason why the upward search is difficult seems to be related to the issue of focus. In the upward search the focus is limited. In the downward search, you are looking for possible functions on one level down, the number of which is known to be unknown. The known function on level n guides the search, but it does not limit the focus of search on one level down. In a sense, the existence of something unknown is also in focus. In the upward search, what you are looking for is a relationship among known constituents, which limit the focus. Once you limit the focus, it is difficult to see possibilities outside of it. Trying out possible relationships among a limited number of functions is a finite task. Once all the possibilities are exhausted, there is little room to keep going. Thus, when an upward search is attempted on a wrongly limited focus, the search is bound to fail, leaving the sense of being stuck to the participants.

This interpretation does not imply the upward search is fundamentally more difficult than the downward search. The downward search itself was not so easy for my subjects (they spent a long time on the problem). What my subjects actually did was an intricate combination of both types of searches. The point is that when an upward search fails, it is more often felt as "being stuck," because of the limited focus it deals with.

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Appendix 1: Details of the experiment

Problem

The claim is that verbs show a kind of elasticity -- a capacity for stretching to cover new situations coupled with a propensity to repound to the preferred meaning when context allows. Consider the image formed by the sentence

(1) The flower kissed the rock.

People report picturing "a daisy drooping over a rock, with its petals pressed against the rock," or "a daffodil blown gently across the rock in a glancing sort of contact." The point to notice is that the image is of a flower and a rock doing something resembling kissing. They do not imagine a flower-like person and a rock-like person engaged in the literal act of kissing. This interpretative choice seems quite unconscious; my informants are mildly surprised when I point out that they preserved the noun-referents and not the literal verb-referent, verb elasticity may arise from a rule, perhaps an implicit, unconscious rule, that it is the verb, not the noun, that is to be metaphorically applied in cases of literal strain. The verb does determine the configuration of the flower and the rock and their relative motion. This is compatible with the view that the verb's role is to convey relational information. It may be that the relationships (including stative relations, changes of state, causality, etc.) conveyed by a verb in its preferred meaning are more durable than the particular actions it conveys.

Exploring this phenomenon further, we note that not all the adapting is done by the verb. The particular flower that is imaged is influenced by the verb <u>kiss</u>. People report picturing a flower with a single blossom, not a composite such as a lilac spring or a geranium. The blossom has a circular face and either radial or fluted petal structure, all of which contribute to the analogy with lips. Thus, although it seems that the verb <u>kissed</u> gives up more of its literal meaning than the nouns <u>flower</u> and <u>rock</u>, it still exerts some influence on the interpretation of the nouns. It can select or construct from among the possible flowers one maximally suitable for the kissing scenario.

This phenomenon of relative mutability of meaning was explored in a set of experiments. If the greater breadth of meaning seen in verbs reflects a productive processing difference, then this difference should be seen in people's treatment of novel sentences.

Experiment 1

<u>Subjects</u>. Forty-eight subjects from University of California San Diego participated.

<u>Materials</u>. Sentences were constructed using nouns and verbs that varied in compatibility with one another (as shown in the Appendix

2). There were eight nouns -- two human, two animate non-human, two concrete, and two abstract. Correspondingly, there were two examples each of verbs that prefer for their subject each kind of noun. The 64 "The noun verbed." sentences that can be made from these eight nouns and verbs were used. Some were normal-sounding (e.g., "The daughter agreed.") and some were odd, with considerable semantic strain (e.g., "The lizard worshiped.").

Procedure. Subjects were asked to paraphrase the sentences in a natural manner (in fact, to imagine that they had overheard the sentence in passing and were trying to decide on the most natural interpretation possible). Each subject paraphrased a set of eight sentences, selected so that no subject received the same noun or verb more than once. There were eight such sentence clusters to make the total of 64 sentences.

Experiment 2

This procedure was designed to compare nouns and verbs in terms of their semantic stability in the original paraphrase task. The measure was how easily a new set of people who were shown the paraphrases could select the nouns (or verbs) that had occurred in the original sentences.

Subjects. Eighty-four college students in the Cambridge area participated as subjects. Half of them were assigned to the Noun Group, while the other half were assigned to the Verb Group.

Materials. The total of 384 paraphrases produced by the first experiment were used as stimulus sentences for the second experiment. They were divided into 6 sets, so that each set contained 64 paraphrases corresponding to the original 64 sentences. Each set contained paraphrases written by all six subjects in Experiment 1.

Procedure. Subjects were divided into two groups, the Noun Group and the Verb Group. The Noun Group subjects were given eight original nouns written on a sheet of paper, and heard a set of 64 paraphrases. After hearing each sentence, they were asked to "guess" which of the original nouns had occurred in each sentence before it was paraphrased. Seven subjects were assigned to each set. The Verb Group subjects were tested under the same procedure, except they were told to guess original verbs rather than nouns.

Appendix 2: Data format

Figure 27 shows the data format used by R to record her subjects' answers. This was available all the time during the statistics interaction.

Green **Paraphrase Retrace Data**

NOUN VERB

1/7/11/79

subject date

Paraphrase Matrix - Green

The noun verbed.

	daughter	politician	mule	lizard	car	lantern	respon- sibility	courage	TOTAL	MEAN
agree	A1 1	H9 1	G17 1	F25 cook 0	E33 1	D41 1	C49 1	B57 succeed 0	6	
worship	B2 limp 0	A10 1	H18 soften 0	G26 1	F34 1	E42 1	D50 agree 0	C58 1	5	
shiver	C3 1	B11 1	A19 1	H27 1	G35 1	F43 1	E51 weaken 0	D59 1	7	
limp	D4 agree 0	C12 1	B20 1	A28 weaken 0	H36 soften 0	G44 1	F52 1	E60 weaken 0	4	
cook	E5 1	D13 weaken 0	G21 1	B29 1	A37 shiver 0	H45 1	C53 weaken 0	F61 1	5	
soften	F6 agree 0	E14 1	D22 1	C30 1	D39 shiver 0	A46 1	H54 1	G62 weaken 0	5	
succeed	C7 1	F15 1	E23 1	D31 1	C39 1	B47 1	A55 agree 0	H63 1	7	
weaken	H8 soften 0	G16 agree 0	F24 1	E32 1	D40 shiver 0	C48 shiver 0	B56 limp 0	A64 1	3	
TOTAL	4	6	7	6	4	7	3	5	GRAND TOTAL 42	GRAND MEAN
MEAN									BELOW DIAG (24) / DIAG (16) / ABOVE DIAG (24)	

"Figure 27. Data" format used by R for her experiment.

Appendix 3: Example coding for the levels of understanding

The following excerpt is for illustrating how the steps and levels were coded on the protocols.

Example excerpt

302 A1: what actually happens is/
that the bobbin is in a little cage (Se)/
303 and the loop gets shoved down (p)/
304 and the cage
305 takes
306 grabs
306 grabs onto that loop (P)/ and
307 flips it over the bobbin
308 A2: hum/
309 A1: like this (P)/
310 and then pulls up (P)/
311 see you flip that
312 this
313 thread over the bobbin (P)/
314 and then if you pull up on that thread (P)/
315 as the needle comes back up (P)/
316 it pulls up (P)/
317 and that
318 the loop then
319 is gonna
320 slip back up here (P)/
321 and eventually will grab on here (P)/ so
322 then the loop
323 grabs on down there (P)/
324 A2: right/
325 A1: and
326 pulls that in (P)/ just like
327 this
328 lock stitch (R)/

All the protocols were first unitized into minimum meaningful units throughout. Slashes (/) on the example denote these unit boundaries. Then, the units were categorized according to its conveyed meanings. These categories are shown in code in parentheses at the end of each unit. The units identified to be not directly relevant to the sewing machine stitch problem did not get these category labels. On the example, "Se" means "setting up," "P" means "process expression," "R" stands for "result expression." Other categories include "Questioning" (e.g., "Is this bobbin thread continuous?"), "Criticisms" (e.g., "That's all very nice/ if I can understand how the bobbin itself works."), and "Judgments" (e.g., "I don't have it quite right I think").

After this categorization, units were grouped together to form higher level units by meaningfully grouping categories. These higher level units correspond to "steps" in the text. For Example, first "setting up" the objects in their proper place, then expressing "processes," and then explain what the "result" of such processes would be is a reasonable sequence of proposing a mechanism as an explanation. The above example is one of such "proposals."

Operationally, the steps are defined as follows (units in parentheses are optional):

Mechanism	Proposed	--	(Setting) + Process + (Result)
	Searched	--	(Setting) + Process + (Result) + Negative Judgment
	Criticized	--	Criticism
	Confirmed	--	(Setting) + Process + (Result) + Positive Judgment
Function	Identified	--	Result
	Questioned	--	Result + Question

The "level" of each step is decided by looking at its main process expression. Each level on the function-mechanism hierarchy used in the text has its main process expression. They roughly correspond to that of the standard function on Figure 10 (the ones on the center of each mechanism): "a stitch is created" for level 0; "two threads interact" for level 1; "the bottom thread goes through the loop of the upper thread" for level 2; "the upper thread loop goes around the bobbin" for level 3; "one side of the loop goes through the back space provided by the bobbin structure" for level 4; and "the bobbin is held by the collar of the hookshaft" for level 5.

In the example, the main process is expressed as "the cage flips the loop over the bobbin." This is judged to be closest to the level 3 expression, "the loop goes around the bobbin." Thus, the example is coded as "Level 3, Mechanism Proposal."

Appendix 4: Key phrases for C-POV coding

The keys include deictic verbs (e.g., come, go) and demonstratives (e.g., this, here). In the list, the key phrases are first grouped together under its agent noun, and in each group, arranged in an alphabetical order, for each C-POV. C-POV codes stands for the following.

G :	Global	: Bird's eye view
LT :	Local, top	: At top side of the machine
LB :	Local, bottom	: At bottom side of the machine
LBt:	LB, top	: At top-front of the bobbin
LBb:	LB, back	: At backside of the bobbin

For "that" and "there," because of the vagueness of how far the point of view should be from the object, a double code (e.g., G/LB) was given. Whenever this happened, the one primarily used in its surroundings were chosen to be the code for that expression.

C-POV coding scheme I.
Deictic verb phrases

(Words in parentheses are optional.)

Key phrases: Object	Verb phrase	C-POV
needle	go back and forth	G
	move	G
	come back (up)	LT
	come (back) up	LT
	go down	LT
	go through hole/material	LT
	(be) push(ed) down	LT
	(be) push(ed) through hole/material	LT
	bring down upper thread/loop	LT -> LB
	come down	LB
	go up	LB
	(be) push(ed) (back) up	LB
upper thread	move	G
	come out of eye	LT
	come out through hole/material	LT
	come back (up)	LT
	come (back) up	LT
	go down	LT
	go through material/hole	LT
	(be) push(ed) down	LT
	(be) push(ed) through hole/material	LT
	be brought down	LT -> LB
	(be) draw(n) down	LT -> LB
	come down	LB
	come out through loop	LB
	go up	LB
	(be) push(ed) up	LB
	(be) push(ed) back up	LB
	come around bobbin	LBt
	come in front of bobbin	LBt
	come back(side) of the bobbin	LBb
	come behind bobbin	LBb
loop	come back (up)	LT
	come (back) up	LT

	go down	LT
	(be) push(ed) down	LT
	(be) push(ed) through hole/material	LT
	(be) draw(n) down	LT -> LB
	be brought down	LT -> LB
	back up	LB
	come down	LB
	go up	LB
	(be) push(ed) (back) up	LB
	come around bobbin	LBt
	come in front of bobbin	LBt
	come back(side) of bobbin	LBb
	come out from behind bobbin	LBb
bottom thread	come out of hole	LT
	come up	LT
	come back	LB
	come out of bobbin	LB
	go up	LB
	(be) push(ed) up	LB
	(be) push(ed) through hole/material	LB
hook	come up	LBt
	go down	LBt
	come around to back	LBb

C-POV coding scheme II.

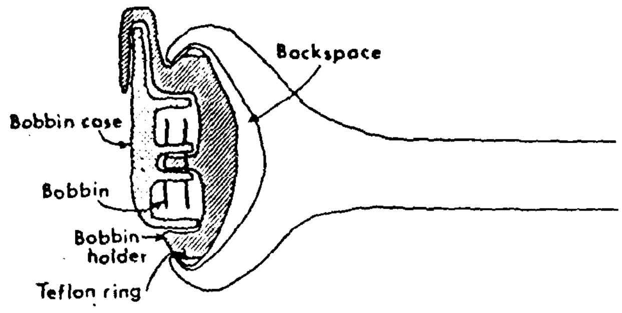
Deictic demonstratives

Key phrases Demonstrative	Used in relation to	C-POV
this/here	cloth/material	LT
	free end of upper thread	LT
	needle [at up position]	LT
	spool of upper thread	LT
	bobbin	LB
	bottom thread	LB
	loop	LB
	needle [at bottom position]	LB
that/there	below	G/LT
	bobbin	G/LT
	bottom thread	G/LT
	loop	G/LT
	needle [at bottom position]	G/LT
	free end of upper thread	G/LB
	needle [at up position]	G/LB
	spool of upper thread	G/LB
up here		LT
down here		LB
underneath here		LB
down (below) there		LT
underneath there		LT
up there		LB

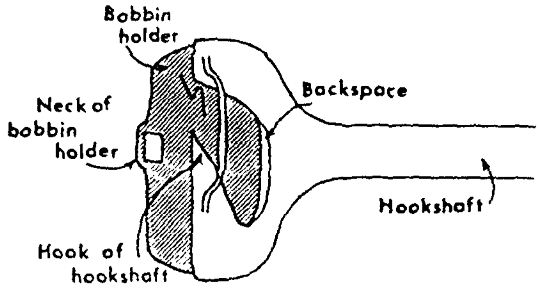
Appendix 5: Nomenclature for parts of the bobbin mechanism

Figure 28 shows names for parts of the bobbin mechanism, as used in the text.

Nomenclature for Bobbin Mechanism Parts



Cross sectional view



Top view

Figure 28. Nomenclature for parts of the bobbin mechanism.

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